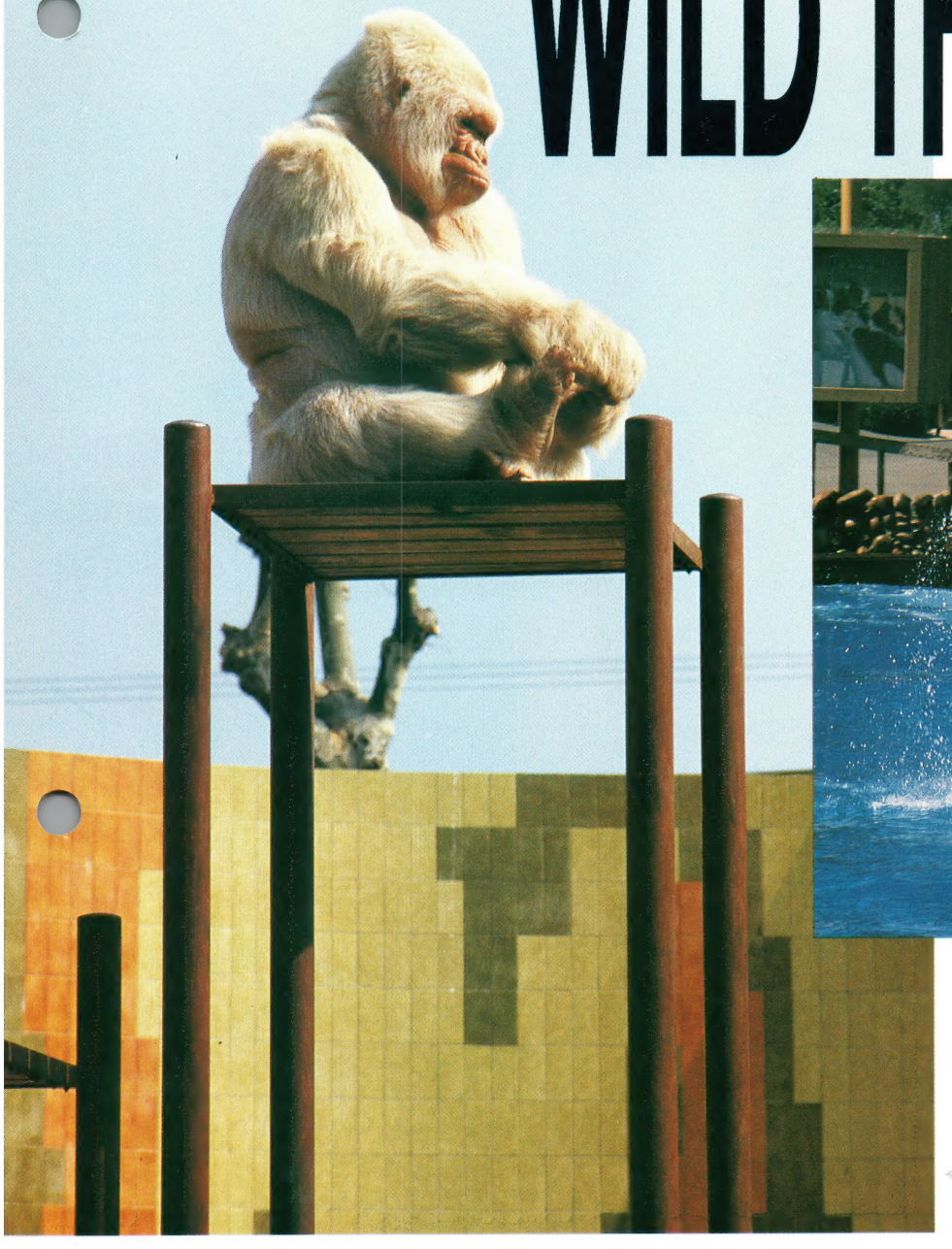
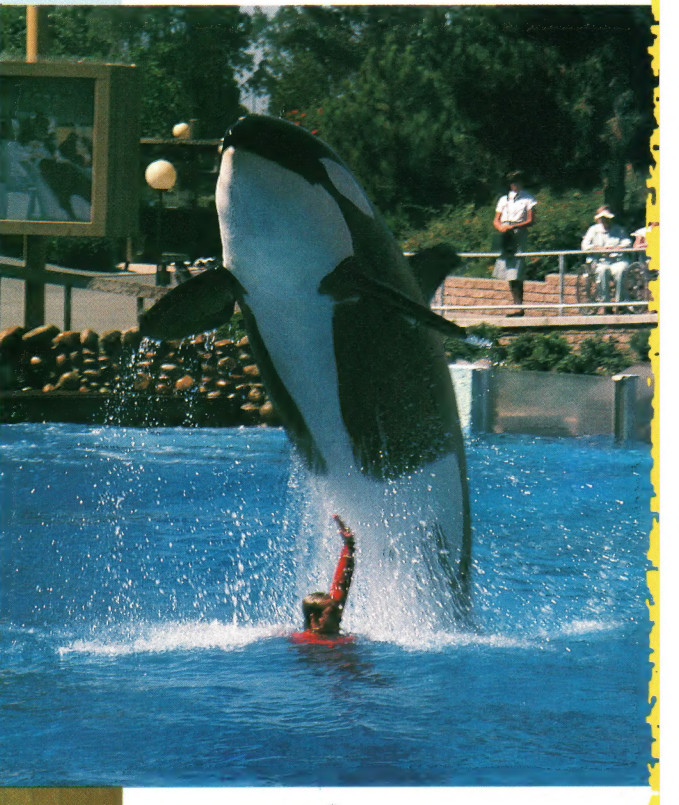
ZOO RESEARCH | BREEDING IN CAPTIVITY | ANIMAL ENCLOSURES

WHERE WILD THINGS ARE





The killer whale *as a performing animal. 'Shamu' has been trained to leap out of the water at Seaworld in San Diego, USA, and perform other tricks.*

Sitting alone *at Spain's Barcelona Zoo, far away from its native jungle, an albino gorilla stares from a platform. In the wild it would remain under cover.*

Frank Lane Picture Agency

ZEFA

MORE THAN 350 MILLION people visit the world's 750 or so zoos each year, and in many countries, zoos regularly feature in the lists of top ten tourist attractions. But are zoos just tourist attractions, or do they serve any scientific purpose?

Modern zoos perform three main roles. First and foremost, they allow scientists to study animals and to find out how they 'work' and live. With this knowledge, organizations can set up proper wildlife conservation and preservation schemes. Biologists can also make comparative studies of animal and human anatomy (structure) and physiology (functioning) to shed light on how the human body works and it can best be treated medically.

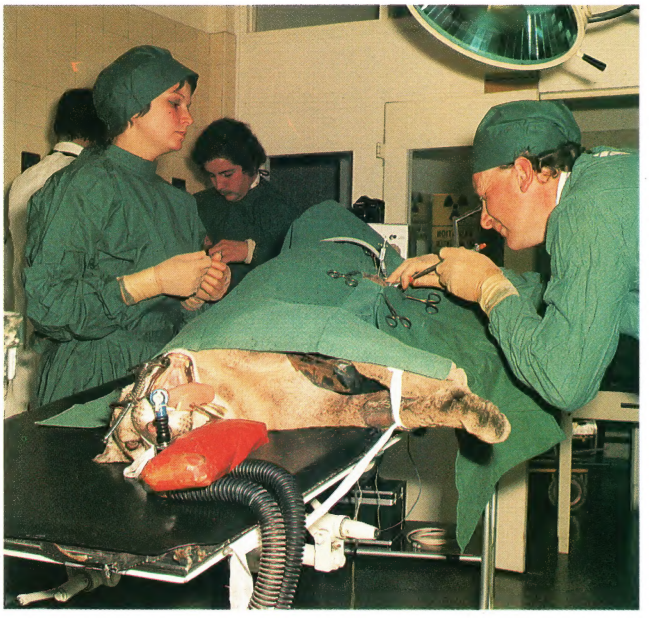
Second, zoos allow species that are threatened with extinction to be increased in number and to be bred in captivity. Hundreds of endangered species have been helped in this way, including the white rhino, mountain gorilla, giant panda and the Californian condor.

Animals such as the Arabian oryx and Père David's deer have been successfully bred in captivity and

PROFILE

THE COSTS OF CARE

Animal	*Cost per year (£)**		
Ant	15	Chimpanzee	750
Toad	30	Gorilla	1,000
Cobra	80	Giraffe	1,800
Squirrel monkey	150	Lion	2,300
Alligator	300	Californian sea lion	3,000
Penguin	350	Koala bear	4,000
Grey wolf	600	Asian elephant	7,000



Zoo Operations Ltd

A zoo vet *looks into the abdomen of a female puma, 'Betsy', at London Zoo using a laparoscope. The most modern zoos have a team of vets who not only care for the animals when they are sick, but also study them to learn more about how they function, to prevent future illnesses.*

returned to the wild. But it is important to make sure that when animals are returned to the wild, they can adapt and thrive, so zoo research helps in this area.

Mating agencies

Breeding programmes involve detailed studies of genetics, and often require the sending of animals from one zoo to another to obtain the best mates, as has been done with giant pandas and other animals. There are international zoo programmes aimed at preserving animals such as tigers for the next 200 years, until the human population has stabilized. The International Species Inventory System – ISIS – is a computerized register based in Minneapolis, USA, that tells zoos around the world which animals are kept where. Now a new British system called NOAH – National Online Animal History – can add details of each animal's pedigree, so that suitable breeding partners can be found without any fear of inbreeding.

The third function of zoos is that they allow the general public to see exotic animals in the flesh and to learn about them at close quarters. This is especially important with young children, who learn more quickly if they are being entertained at the same time.

A large modern zoo such as London Zoo has a huge staff. It employs around 100 research scientists, veterinary surgeons, a behavioural psychologist and, of course, the keepers. The duties of the keepers range from hosing down the elephants and 'mucking out' the tigers, to feeding all the animals with a well-balanced diet. Different animals have to be fed in a variety of ways.

Monkey nuts

Gorillas, for example, like to eat several times a day as well as forage for nuts, while a boa constrictor is content with a couple of rats once a week. Rats, mice and insects are bred at the zoo just for food purposes. Most animals require different vitamin or mineral supplements at some stage, which the keepers must administer. And if a young animal is rejected by its mother, it has to be hand-reared by the keepers.

Gamma/Frank Spooner Pictures

White tiger cubs *are extremely rare. This pair was kept in an incubator for their first few days. They were born among a litter of orange-coloured Bengal tigers at the Hawthorn Circus, USA and now belong to Omaha Zoo. There are only about 60 white tigers in captivity in the world.*

Cruel to be kind?

While zoos serve many useful purposes, the question always arises: Is it cruel to keep animals in cages? With large roaming animals such as lions, tigers and elephants, the answer must to some extent be 'yes'. But if such animals were left in the unprotected wild, they would probably not survive. Thus, as people

Learning to live *with animals: zoologist and author Gerald Durrell shows visitors to Jersey zoo how warm and friendly snakes can be. Durrell is the founder and a director of the Jersey Wildlife Preservation Trust, a unique centre for breeding rare species in captivity. Durrell is keen to teach future generations about the world's animals.*

© Robert Rattner 1984

Phillip Coffey/Jersey Wildlife Preservation Trust

Rex Features

***Zoo enclosures** have been the subject of great controversy for many years. It is now generally accepted that it is cruel to keep large animals such as tigers in small cages (left). Now zoo designers try to surround the animal with at least some of the sights and sounds of its natural environment.*

***The new lion enclosure** at London Zoo, Great Britain, is a good example of modern zoo design. The lions have plenty of room to roam, and are enclosed by a water-filled moat rather than steel bars.*

encroach more and more on wildlife areas, for housing, farming, industry or tourism, zoos are a vital haven for a great many species in real danger of extinction.

However, zoo spaces are limited. There are less than 4,000 places in the world's zoos for tigers, but this includes over 1,000 each of the main species – Siberian, Bengal and Sumatran. This leaves very little room for the other species and cross-breeds, and at a cost of £2,000 per year to keep a tiger, some zoos find themselves having to destroy 'surplus' tigers.

Animal crackers

Many zoos closed their polar bear enclosures when it was discovered that these animals were becoming psychotic because of confinement. Their behaviour was described as 'stereotyped', ranging from meaningless pacing and swaying to self-mutilation.

Polar bears are used to roaming

The Lion Enclosure at London Zoo

Zoo Operations Ltd/John Houghton

over thousands of square kilometres in the wild, and have problems adapting to the confines of a zoo. Even in Washington's Tacoma Zoo, which has one of the most advanced enclosures, the

Rex Features

***Zoo keepers** have to care alike for little and large animals. The baby parrots (left) are being hand-reared, which involves feeding them with a syringe. The elephant (above) likes nothing more on a hot day than being hosed down by its keeper.*

they will be enclosed by a wall of one-way glass through which people can be neither seen nor heard.

Most city zoos have now combined resources with rural nature parks in which the animals can spend some of their time in large open spaces. For example, London Zoo is linked to Whipsnade Park, an area of about 200 hectares. In such areas it is often possible to drive through the enclosures and to watch the animals behaving as if they were in the wild.

Rex Features

PERFORMING ANIMALS

In most countries there are now strict rules about how circus and other performing animals should be looked after, trained and worked, covering areas such as:

- larger cages and exercise pens
- a greater emphasis on training by reward, rather than punishment
- regular inspection by vets

Most performing animals are bred in captivity and know no other life, having never lived in the wild. But animal rights campaigners still claim it is cruel to make animals perform and to keep them in such unnatural conditions.

Phillip Coffey/Jersey Wildlife Preservation Trust

***Lion tamer** – a vet examines Floyd, a 7-year-old lion, under anaesthetic at a zoo in England. Floyd had been bitten on the leg by another lion. Fragments of broken bone were discovered in Floyd's knee, so he was given antibiotics to protect against infection. An operation then removed the bone fragments.*

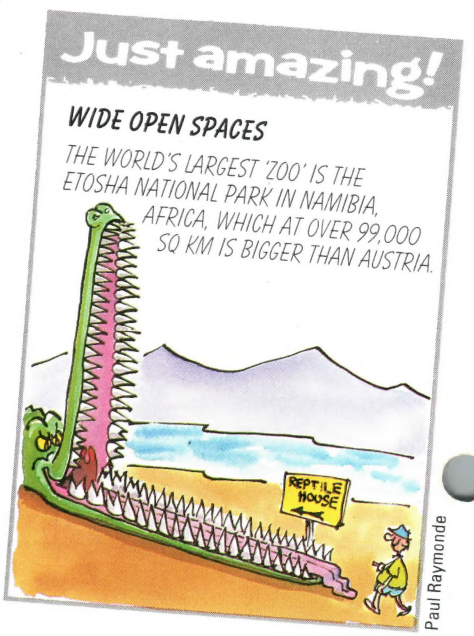
Robert Harding Picture Library

polar bears and elephants show signs of stress.

Britain's Bristol Zoo is showing a way forward by hiring a behavioural psychologist to find ways to keep its polar bears happy. They are now given toys to play with and encouraged to forage for their food. The bears' symptoms of stereotyped behaviour have since disappeared.

Home from home

But for many other animals, zoo managers and zoo architects have succeeded in improving their quality of life in captivity by building enclosures that re-create some of their natural environment. The new gorilla house at London Zoo plays recorded bird songs and the sounds of other gorillas. It also has a sprinkler system to simulate the rainfall of the gorillas' natural habitat. Because gorillas are naturally shy and so very wary of humans,



Paul Raymonde

Cross-section *of a plant stem reveals air-filled pith cells surrounding the plant's food and water carrying tubes (the compact bundle in the centre).*

BIOLOGICAL FACTORIES

EVERY LIVING ORGANISM IS made up of cells. Some cells live alone as microscopic creatures; others form larger organisms as diverse as a tiny flower and a whale.

An animal is made up of many different types of cell. Of the 75 million million cells in the human body, most are specialized to carry out one particular job. For example:

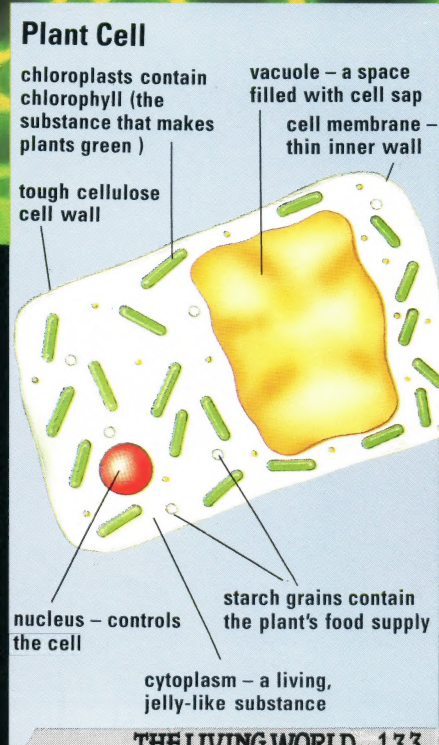
- nerve cells are long and thin – nerve impulses travel along them
- skin cells are flat – they protect the body
- blood cells are disc-shaped – they carry oxygen around the body

Specialized cells, when grouped together in the human body and other organisms, are called tissues.

Chemicals of life

In spite of their different tasks all cells work in the same basic way – along the lines of a factory. A continuous flow of raw materials enters the cell. These are converted into chemicals, such as hormones or enzymes, which are essential to the basic functioning of the body. They are then transported to other cells or used within the same cell.

No cell lives for ever. Some cells such as white blood cells, live for a

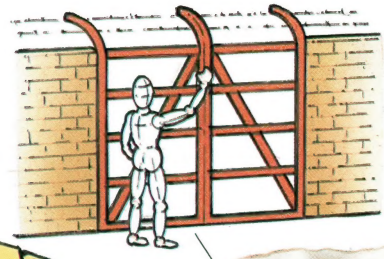


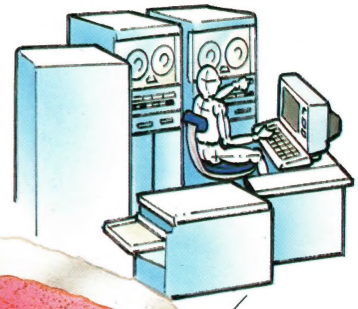
Jayanandan/Science Photo Library

John Houghton

Animal Cell

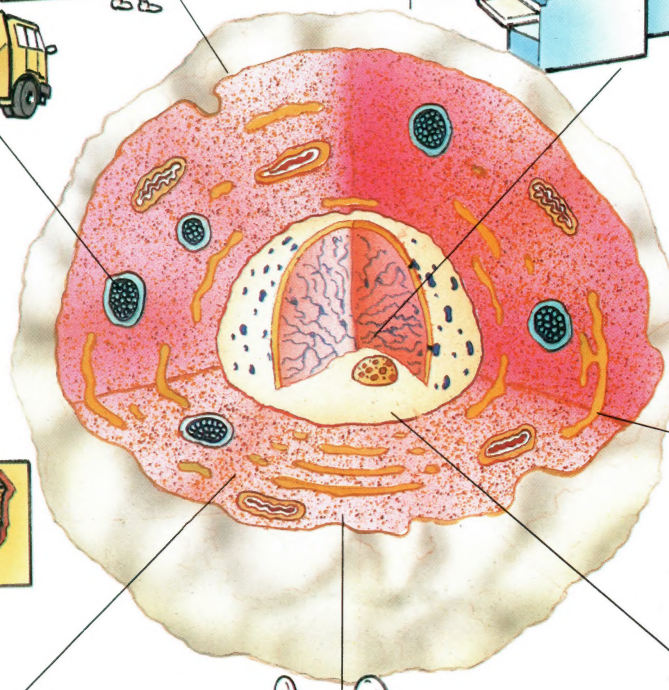
the cell membrane is the 'factory wall' – it controls substances that enter and exit the cell ▶



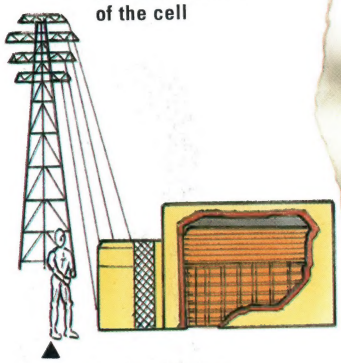


◀ the nucleus is the 'control room' – it determines and controls all the cell's activities and sends instructions to other parts of the cell

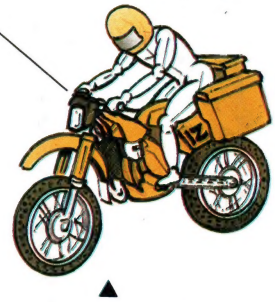
▲ lysosomes are 'refuse collectors' that break down waste products and send them out of the cell



▲ the endoplasmic recticulum is the 'production plant' – it contains ribosomes: 'machines' that produce the chemicals the body requires

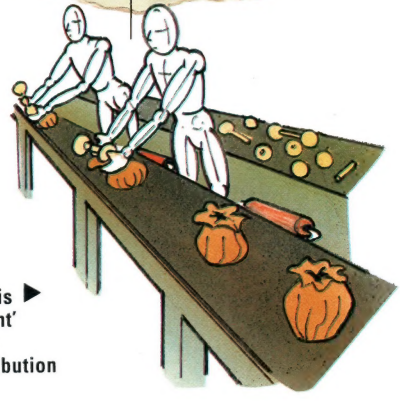


▲ the mitochondria are 'power generators' – they convert food into energy



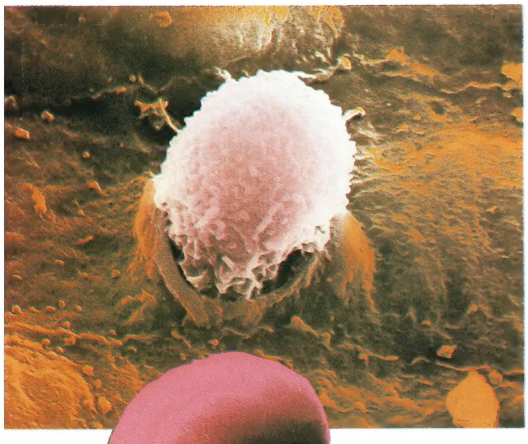
▲ RNA are the 'messengers' that carry instructions from the nucleus to other parts of the cell and take information back to the nucleus

the cytoplasm is the environment in which all parts of the cell are suspended



the golgi complex is the 'packaging plant' where proteins are packaged for distribution ▶

John Houghton



NIBSC/Science Photo Library

few days. Others, nerve cells for instance, can live for over 100 years. In some cases, dead cells are replaced by new ones in a process known as cell division. Some cells, such as human brain cells, are never replaced.

Animal or vegetable?

Plant cells are bigger than animal cells and are usually rectangular in shape. They are enclosed in a layer of cellulose and often contain starch grains and chlorophyll. Animal cells have no cellulose wrapper and never contain chlorophyll or starch grains.

Blood *consists of a liquid called plasma, in which float red blood cells (1), white blood cells (2) and platelets (3). Platelets help blood to clot in wounds. A white blood cell exits through the wall of a blood vessel (top left).*

Just amazing!

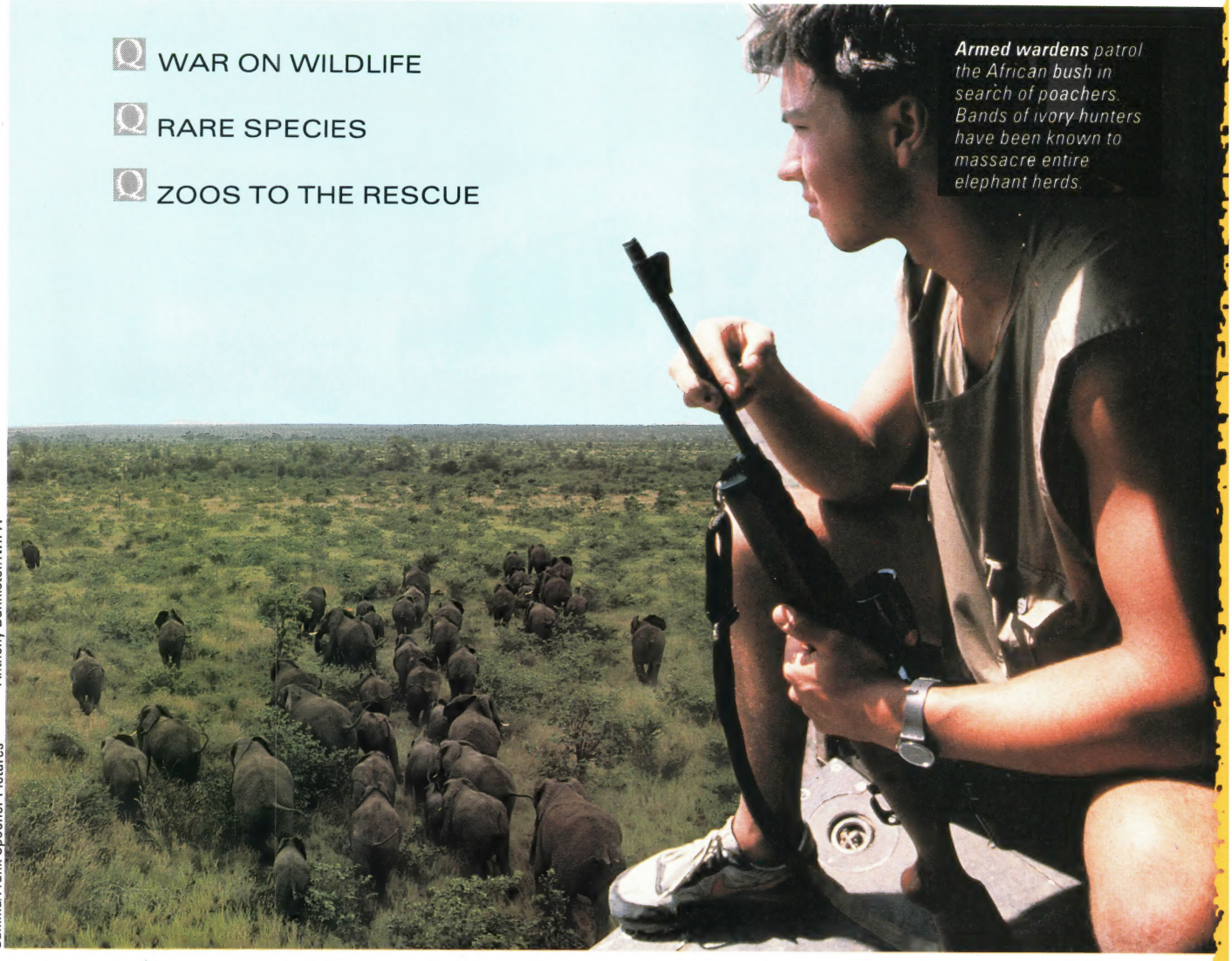
OUTSIZE CELLS

IF A MAN INCREASED IN SIZE BY A MILLION TIMES EACH OF HIS CELLS WOULD ONLY BE THE SIZE OF A TENNIS BALL.

Paul Raymonde

ANIMAL WATCH

- WAR ON WILDLIFE
- RARE SPECIES
- ZOOS TO THE RESCUE



***Armed wardens** patrol the African bush in search of poachers. Bands of ivory hunters have been known to massacre entire elephant herds.*

Anthony Bannister/NHPA

Gamma/Frank Spooner Pictures

POACHING HAS BECOME A multi-million-pound industry. Many animal and plant species on the verge of extinction are illegally slaughtered every year.

But at last, as countries begin to take action against the ruthless killers, the hunters have become the hunted. In some of the biggest game reserves in Africa, rangers armed with semi-automatic rifles are ordered to shoot on sight anyone caught killing protected wildlife.

Elephants are among the most threatened creatures because of their ivory tusks. Ivory, which is made of a similar substance as teeth, is exported, carved into trinkets and sold at very high prices to tourists in countries such as Hong Kong and Japan.

The poachers, who are increasingly well armed and organized, can earn what to them would be a year's income from selling one set of tusks, for around $220 per kg.

Deadly demand

To satisfy the demand, many more elephants must be killed nowadays than in the past. This is because the majority of large bull elephants — whose tusks can reach several metres in length and weigh up to 80 kg — have been shot.

PLANT POACHING

Like animals, plants are also poached for their beauty and value. In June 1989, a Briton, Henry Azadehdel, was sentenced to one year in prison for smuggling hundreds of rare, wild orchids into the country. Collectors around the world will pay high prices for these beautiful flowers, plundered from tropical jungles. A British orchid, the lady's slipper, has also suffered. It once grew in the North of England, until Victorian gardeners and orchid fanciers started collecting it in large numbers. Today, a single, closely guarded plant is all that survives in the wild.

Peter Davey/Bruce Coleman Ltd

***Ivory poachers** hack off elephant tusks, leaving carcasses to rot. Stockpiled tusks ready for export are sometimes discovered and are immediately destroyed (below).*

Jonathan Scott/Planet Earth Pictures

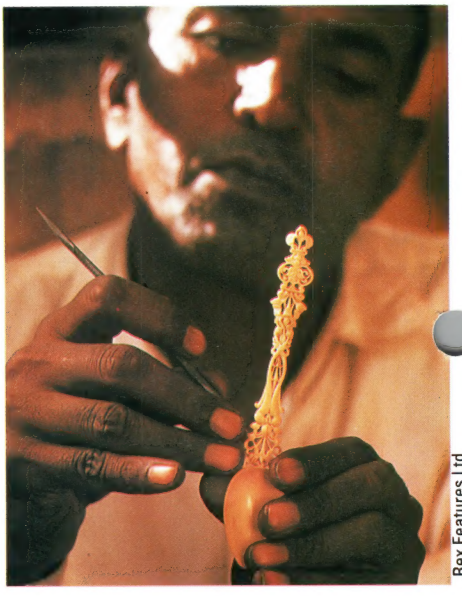
Many nations are members of CITES (the Convention on International Trade in Endangered Species of Wild Flora and Fauna). This supports a worldwide ban on the export of ivory. But not all countries agree that stopping the ivory trade is the best way to protect the elephant.

Legal killing

Game wardens in South Africa and Zimbabwe, for instance, legally kill a certain number of elephants each year. The meat goes to local people; skin and ivory to the international trade. Money from these exports is ploughed back into conservation. These nations claim that, as a result, their elephant populations are rising.

Countries in East Africa, however, such as Kenya and Tanzania, are vigorously opposed to the sale of ivory. These two countries have been worst affected by poaching. Since 1973, Kenya has lost 72 per cent of its elephants within protected areas, and 92 per cent of those outside. Now, however, it has stepped up its war against the poachers by employing more game wardens armed with military hardware. Over the next few years it should become clear which method – legal culling or total protection – has achieved the best results for the elephant.

***Most tusks** are shipped out of Africa to be worked into jewellery, dagger handles, piano keys and other artefacts.*



Rex Features Ltd

Africa's Ivory Trade Routes

Environmental Investigation Agency/Lionel Barrance

Many species are now on the very brink of extinction because of poaching and the destruction of their natural habitats by Man. The world's rhinoceros population has been devastated. Tragically, the only reason this animal is killed is so that its horn can be carved into ornamental dagger handles or powdered to make an aphrodisiac, or love potion. Rhino horns are made of matted hair – a substance which has been scientifically proved to have no aphrodisiac quality at all.

Slaughter

A solitary beast, the African rhino has had its numbers slashed from 65,000 in the late 1960s to less than 3,500 today. At the present rate of decline, it will be extinct in the wild by the end of this century.

***Most of Africa's ivory** goes to Japan and Hong Kong. The amount fell from 900 tonnes in 1985 to 300 tonnes in 1988, but elephants still face extinction.*

THE VANISHING WHALE

The biggest animal that has ever lived, the blue whale, may soon be just a memory. Only 22 blue whales were sighted in southern oceans between 1983 and 1989, suggesting that their worldwide population may be less than 2,000. This compares with an estimated 250,000 before hunting began in 1890. Other species of great whale, such as the fin, sperm and humpback, have fared little better. It may be that their numbers are now so low that they will never recover. Even so, some countries including Japan, Iceland and Norway, continue to hunt whales.

Francois Gohier/Ardea London

1987, a similar survey found none. Poaching and destruction of the forests in which they lived have wiped out this species in the wild.

A similar fate threatens the great apes – chimpanzees and gorillas in Africa, and orang-utans in Asia. Most endangered of all is the mountain gorilla, of which only about 500 are left in two tiny areas of central Africa.

In the future it may be that zoos represent the last hope for species facing extinction. Already there have been a number of attempts to reintroduce endangered animals into the wild that have been bred in captivity. But this is much easier with some species than others.

The reintroduction of the Arabian oryx, for instance, has been a great success. Hunters exterminated the last wild herds of this animal in 1972, but biologists in America managed to preserve and build up a herd in captivity. By 1984, they were able to release 21 oryx in two separate groups in the desert of central Oman. Their numbers are now increasing.

Just amazing!

MAMMOTH TASK

WEST GERMAN IVORY CARVERS, FACED WITH A BAN ON IMPORTED ELEPHANT TUSKS, HAVE COME UP WITH AN UNUSUAL ALTERNATIVE. THEY PLAN TO USE IVORY FROM 20,000-YEAR-OLD MAMMOTHS FOUND FROZEN IN SIBERIA!

Paul Raymonde

As a last desperate measure, game wardens in north-west Namibia have begun darting the remaining desert black rhinos with tranquillizers and then sawing off their horns to dissuade poachers. Unfortunately, without their horns rhinos are unable to defend themselves.

Wiped out

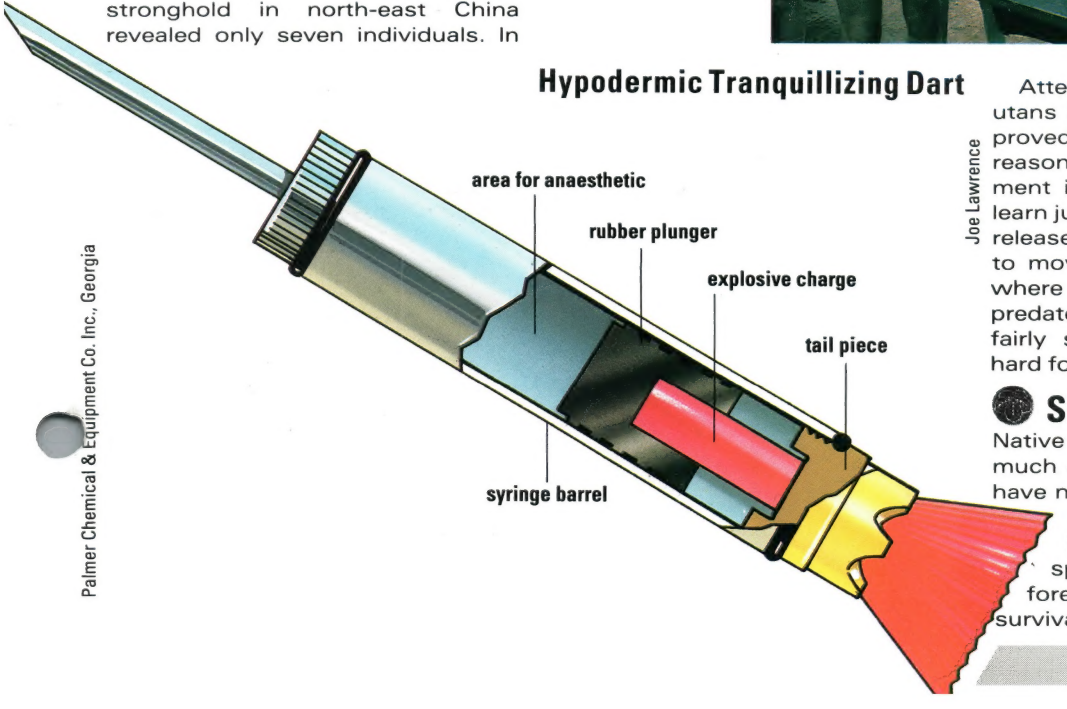
In other cases of threatened wildlife, help may already be too late. A 1970s survey of Manchurian tigers in their last remaining stronghold in north-east China revealed only seven individuals. In

***A wound** is treated by game reserve wardens, who are in the front line in the fight against poaching.*

***High-powered darts** fired from special guns are used by wardens to capture large animals that need veterinary care.*

Rafi Ben Shahar/Oxford Scientific Films

Hypodermic Tranquillizing Dart



Palmer Chemical & Equipment Co. Inc., Georgia

Attempts to reintroduce orang utans into the wild, however, have proved far more difficult. One reason is that the orang's environment is complex – it has a lot to learn just simply to stay alive. Newly released orangs, for example, tend to move about on the forest floor where they are easy targets for predators. They also range over a fairly small area, which makes it hard for them to find enough to eat.

Joe Lawrence

Survival

Native orangs, by contrast, spend much of their time in the trees and have no fear of wandering throughout a territory of 2–3 sq. km. If captive animals can spend time with wild ones before release, their chances of survival greatly increase.

David Curl/OSF

The Black Lemur *lives in the humid forests of Madagascar. It is threatened by the spread of agriculture, logging and fires.*

Salmon-crested cockatoos, *found on the Indonesian island of Seram, are facing extinction because they are prized as cage birds.*

Alain Compost Bruce Coleman Ltd

The Philippines eagle *is threatened by deforestation. Its slow flight also makes it an easy target for hunters.*

Neil Rettig WWF

Bruce Coleman Ltd

The orang-utan *population has been severely reduced by deforestation. Less than 2,000 survive in the wild.*

Alan & Sandy Carey

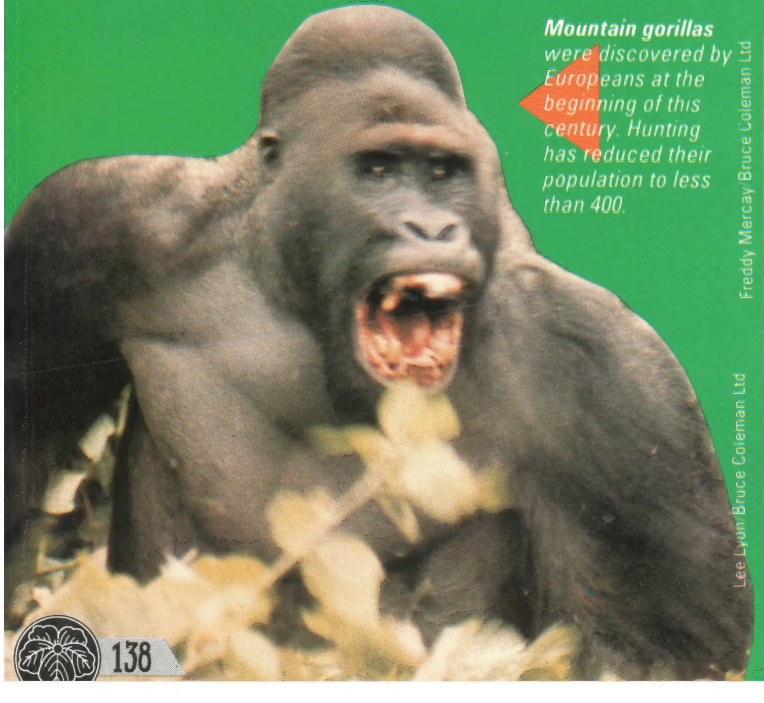
RJB Goodale OSF

The common rabbit-bandicoot *is found in the arid areas of Western Australia. Once hunted for its pelt, it is now close to extinction.*

Leopards *have been hunted for centuries for their much-valued fur. The Chinese leopard is now a protected species.*

Giant pandas, *first discovered in the 1890s, live in the mountain forests of China. Less than 1,000 survive in the wild.*

Mountain gorillas *were discovered by Europeans at the beginning of this century. Hunting has reduced their population to less than 400.*



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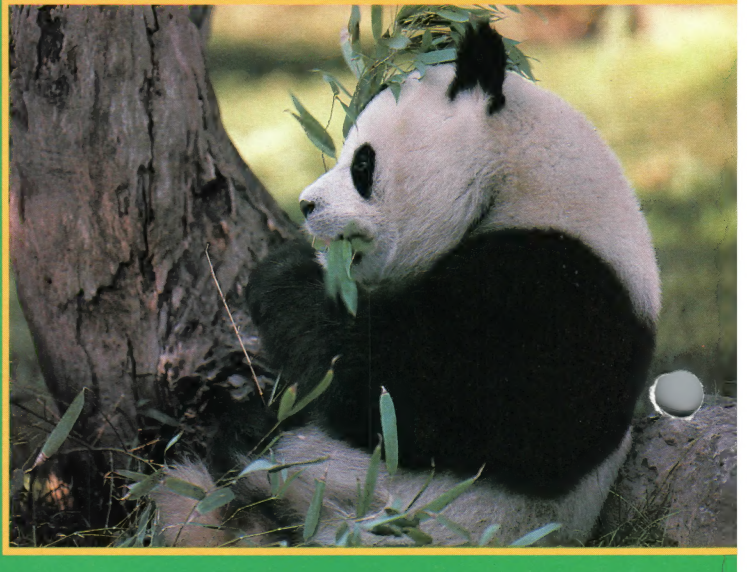

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CAPTURING PREY | ELECTRIC SHOCKS | ARTICULATED JAWS

EARTHLY MONSTERS

CREATURES THAT LOOK monstrous have always exerted a fascination and have been the inspiration for many horror films, and books. Yet many of these animals are not as fearsome as fiction and folklore would have us believe.

Few creatures are as feared – and as fearsome – as sharks and their close relatives, mantas and rays. The most awesome of these fish, the great white shark, inspired author Peter Benchley to write the book and film *Jaws*. Equipped with a huge, crescent-shaped mouth, armed with an array of jagged teeth, the great white is a killing machine. This shark can grow to a massive length of over 30 metres and weigh up to half a tonne.

Maneater

The great white shark also popularly known as the maneater, feeds mainly on seals and porpoises, but will eat just about anything to satisfy its enormous appetite.

There are about 100 shark attacks on people each year, most of which take place in shallow, warm water. The shark usually surprises its victim with one huge bite, then often retreats briefly before returning for the kill. Great whites have been known to jump out of the water to attack fishermen. Sharks have even been known to attack each other in a frenzy of feeding.

The 'devilfish' mentioned in ancient mariners' tales is the Pacific manta ray. This can grow to 6

***Bearded dragons** ward off enemies by expanding their mouth to emphasize their pointed scales. Other lizards have similar deterrent displays.*

Fritz Prenzel/Bruce Coleman Ltd

***Spotting prey** is no problem for the wolf spider – it uses one or all of its eight eyes! Some wolf spiders measure up to 250 mm across. Male wolf spiders use their legs to signal to prospective mates.*

Anthony Bannister/NHPA

across and weigh 1,600 kg. It gets its name from the two horn-like fins that project forwards from its head. With its wide, wing-like pectoral fins and its long, whip-like tail that has sharp spines at its base, the manta is an awesome creature. However, it feeds on plankton and small fish, sifting them from the water as it swims along. Some much smaller rays, such as the torpedo ray, can administer electric shocks to stun prey and to defend themselves.

Deep-sea monsters

Jules Verne, in his novel *20,000 Leagues Under the Sea*, described how the submarine *Nautilus* was attacked by a giant squid. Such deep-sea monsters do exist, although they are more likely to attack their real-life enemy, the sperm whale, than a submarine or a person. Squids' bodies can measure up to 6 metres long, from which project eight arms, and two longer tentacles 11–13 metres long. Giant squid live in deep waters, feeding on fish and smaller squid. They seize their victims with their arms and tentacles, paralyse them with poison, then bite off and swallow small pieces of flesh. In encounters with sperm whales, squid often inflict deep wounds.

Octopuses, like squid, have sucker-bearing arms that they use to capture prey. However octopuses are smaller animals – their tentacles rarely exceed 10 metres.They emerge from rock crevices to attack their prey. Like squids they squirt ink into the water to deter predators. They have been known to seize swimmers, but more out of curiosity than agression. Unlike squids, octopuses can subdue their prey with a poisonous bite.

Marty Snyderman/Planet Earth Pictures

***The great white shark** has a bite 300 times stronger than a human's. An animal 2.5 metres long can exert a pressure of almost 3 tonnes per sq/cm. Great white sharks can reach over 10 metres in length.*

Monster snakes

Some snakes, particularly non-poisonous pythons and anacondas, grow to monstrous proportions. The Indian python can reach 6.5 metres in length. The longest recorded python, shot in the Malay Archipelago, measured 10 metres. Non-poisonous snakes kill their prey by suffocation, winding coils of their body around the victim and literally squeezing the life out of it.

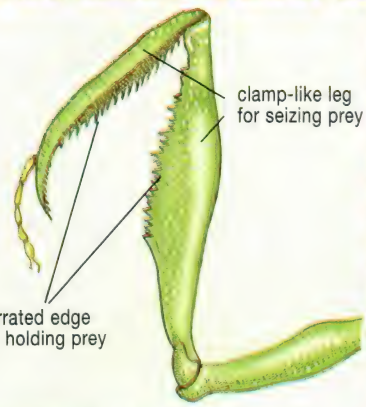
Poison

The largest venomous snake in the world is the king cobra. Fully-grown animals average 3.9 metres. Venomous snakes, such as adders, vipers and rattlesnakes, kill their prey by injecting them with poison from long fangs. When the snake is on the attack, the fangs are extended and point forward. Snakes usually have to inflict one stab to inject a dose of

THE PRAYING MANTIS – A HIDDEN HUNTER

Like many insects, the praying mantis is shaped and coloured to blend in with its background. Many are brown or green to match the foliage where they sit motionless, waiting for prey. The mantis stands on its middle and hind legs with the forelegs raised, as if in prayer. Its front pair of limbs are jointed rather like a penknife, with a sharp serrated edge designed to seize and hold the unfortunate victim. Mantids are slow-moving, which is why they tend not to pursue their prey but wait till it strays within reach. They live on flies, grasshoppers and caterpillars, and the voracious female eats the male during or after mating. The larger South American species attack small frogs, lizards and birds.

David Overcash/Bruce Coleman Ltd



Foreleg of the Mantis

John Houghton

Weintraub Film Library/BFI

Komodo dragons *are the largest lizards in the world. A true relic of prehistory, the Komodo will devour goats and deer. Man-made monsters (left) are often modelled on real-life reptiles.*

poison. When the snake closes its mouth, the fangs fold back into a recess in the roof of the mouth. The larger snakes will prey on each other. The black-headed python specializes in killing other snakes – even the most venomous species.

Snakebite

About 30,000 people die from snakebites each year. Despite this, most snakes are not aggressive towards animals and will not attack unless threatened. Many of their threatening gestures, such as hissing and rattling tails, are intended to ward off predators.

Looking like a spider and measuring up to 8 metres between the tips of its outstretched legs, the Japanese spider crab is feared by fishermen who occasionally catch one in their nets. It commands great respect as it can give a nasty nip with its pincers.

The Birds and *Return of the Vampire* are just two films in which winged creatures are depicted as monsters – and with good reason to some extent. Many types of bee fly in swarms and readily sting people who threaten them. In one case, a young Zimbabwean was stung 2,243 times by a swarm of wild bees. Incredibly, he made a complete recovery.

Philippa Scot/NHPA

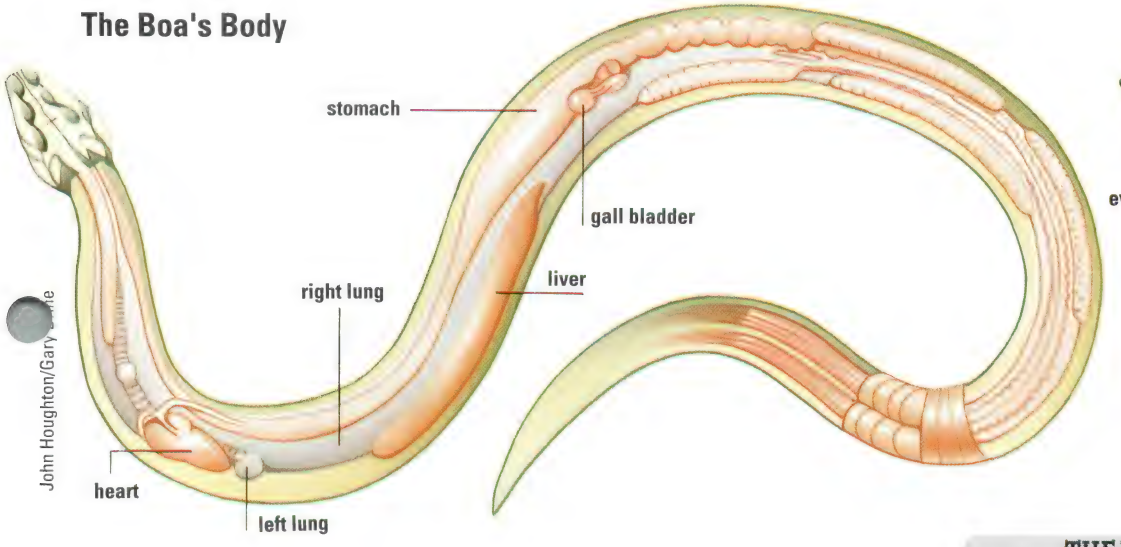
Killer bees

The most dangerous species is the so-called 'killer bee', which was the result of genetic experiments with African bees. In the 1950s, 26 colonies of killer bees escaped from a research centre in Brazil. They have since spread throughout South America and now outnumber normal honeybees. Although their sting is no more lethal, killer bees will attack in much greater numbers and continue

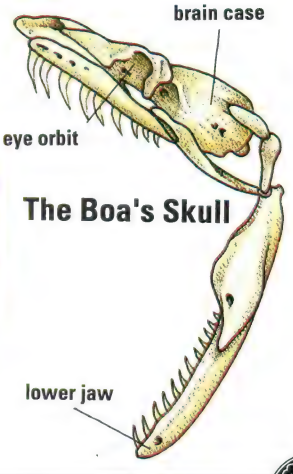
J.Mackinnon/Planet Earth Pictures

The jaws *of a snake (below right) are only loosely attached to each other, allowing the snake to swallow large prey whole (right). Large non-venomous snakes, such as boas and anacondas, prey on animals as big as antelopes and deer.*

The Boa's Body



John Houghton/Gary [illegible]



The Boa's Skull

for up to half an hour. Normal honey bees will defend a few metres surrounding a colony, and attack only when severely provoked.

Attack

Killer bees will defend a 200-300 metre area and are much more likely to attack if threatened. An estimated 40 people have died since the bees first escaped.

Blood-sucking vampire bats also conjure up truly gruesome images. Yet contrary to common folklore, these winged mammals, which are only about 7 to 10 cm long, feed on the blood of horses, cattle and birds, and only occasionally on the blood of humans. The bats attack their victims while they are asleep, sucking the blood from a bite they make on the neck or leg. The real danger of vampire bats, though, is the deadly diseases such as rabies that they transmit while feeding.

Gunter Ziesler/Bruce Coleman Ltd

The vampire bat *makes an incision in its sleeping prey's skin with two razor-sharp teeth (left), then laps up the blood. These bats each drink about 26 litres of blood a year.*

Venomous spiders

Tarantula is the name commonly ascribed to any large, hairy, poisonous spider. All spiders use venom to paralyse their prey, though only a few are powerful enough to pierce human skin. One that can is the funnel-web spider of Australia, one of the most poisonous spiders in the world. This species – so called because it makes its lair by spinning a tube of silk in a hole or crevice – strikes out at any insect or animal that comes near. Its bite is highly toxic and nearly always fatal.

Stephen Dalton/NHPA

Horror

When not using spiders, film producers often use snakes, lizards and other reptiles to create fear and horror. Think of some of the scenes in *Raiders of the Lost Ark* and *Romancing the Stone*. In *The Lost World* live reptiles were cleverly disguised as dinosaurs in an attempt to make the film's various monsters move more naturalistically.

Species such as the Komodo dragon are indeed monster lizards. Komodos lived unknown to Western man on a group of small Indonesian islands until 1912, when a pioneer airman made a crash landing on one of the islands. He was horrified to discover large numbers of these real-life carnivorous dragons.

Even honey bees *look like alien creatures when viewed close up. This worker honey bee, unlike the queen bee or drone, has a spoon-shaped jaw, minus serrations, so that it can mould wax.*

Dr J. Burgess/Science Photo Library

FIGHTING PHOBIAS

Many people have an understandable fear of creatures such as snakes and spiders. But when that fear becomes so intense and irrational as to change a person's behaviour, it is called a phobia. This sometimes stems from bad experiences in a person's past or even a single incident in early childhood the sufferer can no longer remember. Psychotherapists may treat the disorder with hypnosis, by helping the patient recall the experience in their subconcious. In some cases, the phobic person is gradually faced with the animal that they fear. For instance, an arachnophobe – someone with an irrational fear of spiders – will be shown photographs of spiders and eventually gently encouraged to handle one.

Just amazing!

SLOW CENTURY

THE SLOWEST GROWING SPECIES IN THE ANIMAL KINGDOM IS THE DEEP SEA CLAM – TANDARIA CALLISTIFORMIS – WHICH TAKES 100 YEARS TO REACH A LENGTH OF 8MM.

Paul Raymonde

GROWING STRUCTURES

S & J Walter Science Photo Library

David Barrett/Planet Earth Pictures

Cacti have thick-walled cells (magnified, far left) to provide support for their robust stems. Thick, leathery skin prevents water loss, and sharp spines, instead of leaves, protect the plant from grazing animals.

PLANTS PROVIDE A SUPERB example of living engineering, from their roots, which seek out water and minerals in the soil, to their leaves, which capture the energy of sunlight.

The green in the leaves and stems of most plants is caused by a remarkable chemical called chlorophyll. This is the vital substance that enables plants to trap energy from the Sun and use it in a process known as photosynthesis.

Water and minerals enter the plant through its roots, then travel up the stem through a series of fine tubes. These tubes eventually run out into the leaves via a network of veins

On the underside of a leaf are many tiny openings, or stomata, through which carbon dioxide from the air can enter. The leaf's upper surface, where the cells are very rich in chlorophyll, acts like a tiny solar panel. Having trapped the Sun's energy, the plant uses it to convert carbon dioxide and water into glucose - a type of sugar - and oxygen. The glucose then serves as an internal energy store to help the plant manufacture still more complex substances, such as proteins, that it needs to live and grow.

Plant structure

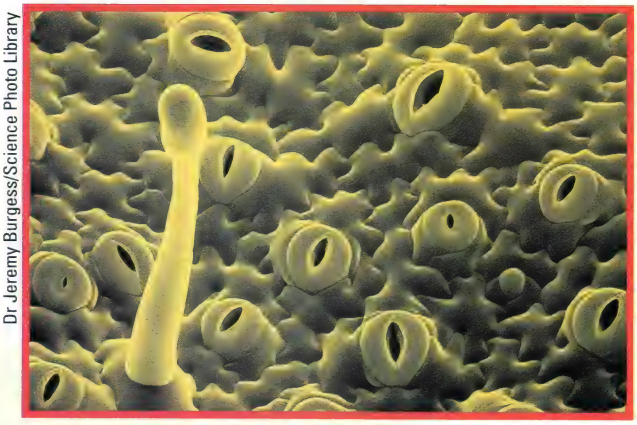
As well as being an efficient miniature factory, a plant is also a brilliantly engineered structure. Its stem and roots serve the dual purpose of transporting fluids and of supporting the leaves and other important parts, such as flowers and fruits.

Roots come in a variety of forms.

A tap root, for example, is a single, large root that anchors the plant and from which smaller, secondary roots grow. In the case of a carrot plant, the tap root is the entire orange part that we eat. A fibrous root system, on the other hand, such as that of grass or sagurro cactus, consists of a large number of equal-sized roots.

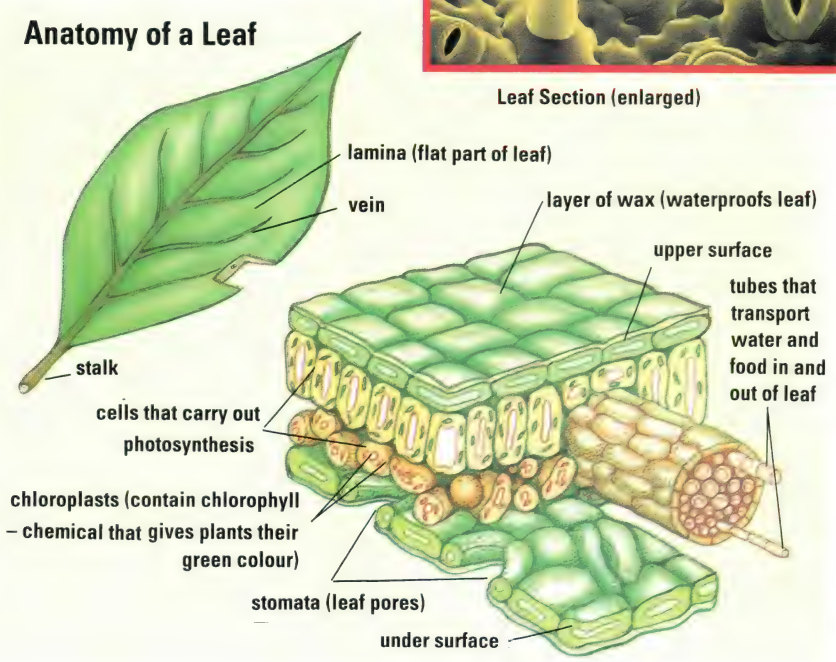
Other types of plant, such as ivy, have roots below and above ground level. These climbing, aerial roots are often capable of absorbing moisture from the air - another instance of a plant structure doing more than one job. A fourth kind of root, called a prop root, grows down from a stem and then into the ground. This gives extra support and anchorage to plants such as mangroves, which are common in shallow tropical coastal waters.

Many of the most cleverly engineered parts of a plant are concerned with reproduction. Plants have a bewildering number of ways to ensure that copies of themselves are made and that their species continues to survive.



Dr Jeremy Burgess/Science Photo Library

***Plants** need sunlight, carbon dioxide and water to make food. This process – called photosynthesis – takes place in the leaves. Energy from sunlight is absorbed by chlorophyll. Carbon dioxide enters through tiny pores, or stomata, on the underside of the leaf (magnified left, 100 times). Water from the soil rises up via tubes in the stem.*



Pollination

Flowers containing the male and female reproductive parts, are frequently coloured or scented to attract certain kinds of insects. The flower provides not only a landing pad but also a sweet substance called nectar that bees and butterflies feed upon. Unknowingly, the insects also pollinate the flowers. They do this by transferring pollen grains from the male organs, or stamens, of one flower to the female organs, known as carpels or pistils, of another.

Once pollinated, the female structure begins to develop into a fruit containing one or more seeds. Essentially, the fruit is a vehicle to help the seeds inside it find a place where they can grow. Some fruits, like those of the broom plant, literally explode, shooting the seeds out.

INSECT EATERS

John Houghton

Claude Nuridsany & Marie Perennou/SPL

Some plants, such as the venus fly trap and the sundew plant (above), are carnivorous. The sundew lures insects with glistening droplets at the tips of its tentacles. As the victim struggles to escape, the sticky tentacles curl over, gluing it to the leaf. Enzymes digest the meal and the products are absorbed by the leaf. It takes a sundew a whole day to eat a single mosquito.

Just amazing!

ROOTS THAT RUN RIOT

UP TO 350 PROP ROOTS HANG DOWN FROM INDIAN BANYAN TREES, MAKING THEM WIDE ENOUGH TO COVER AN ENTIRE MARKET PLACE!

Paul Raymonde

Claude Nuridsany & Marie Perennou/SPL

Poppy capsules, on the other hand, have tiny holes in the top like a pepper shaker, so that they release seeds whenever the wind blows them. Others, such as the bramble or apple tree, produce fruits which are eaten by a variety of animals. The seeds cannot be digested and are passed out in droppings, usually far away from the parent plant.

***The seeds of the wild geranium** are dispersed by mechanical means. Strips of fibre wind themselves around the spear-like seed pods. This causes the seed to become detached from the geranium's flower and to be dispersed by the wind.*

- TRAINING HOUNDS
- STAG HUNTING
- SHOTGUNS

THE HUNT

THE HUNTING CRUELTY debate is one of the most bitter controversial areas in sport. To some, stalking and killing their chosen quarry is not only enjoyable, but essential to preserving wildlife's natural balance. Yet others see blood sports as cruel and unnecessary.

Of all the blood sports, fox-hunting arouses the most passion – both for and against. Foxes are hunted as vermin and for their pelts in many European countries. But in Britain, the US and Australia, foxhunting has developed as a fieldsport – carried out on horseback and with a pack of hounds. Huntsmen claim that fox-hunting is not cruel, as the hound will snap the fox's spinal cord with its first bite, killing it instantly. But some people dispute this, claiming that the fox suffers a lingering, painful, death.

Training the pack

Foxhounds are trained from birth to hunt and kill, and do not make good pets - they have been known to turn on people. Between February and May of each year, new litters of hounds are bred. They are fed on a basic diet of porridge and meat, which may include 'fallen stock' – dead cows and sheep from local farms. At the age of eight to ten weeks they are taken to farms where they are allowed to roam and play. During the following summer, kennel staff take the pack out for walks through country lanes and across fields. At this stage the hounds will be 'on couples' – two collars connected by a chain that is used to link the hounds in pairs. A young hound is partnered with an experienced old hound. In this way he learns what the various commands mean and becomes more disciplined.

In the course of the summer the daily distances increase. Packs are

***Foxhounds** are controlled by 'whippers-in' who try to prevent the pack from straying off to chase other animals or crossing busy roads.*

***The harder a fox runs,** the more scent it gives off from its glands and pads. But only one out of every four hunts ends with a fox being caught and killed.*

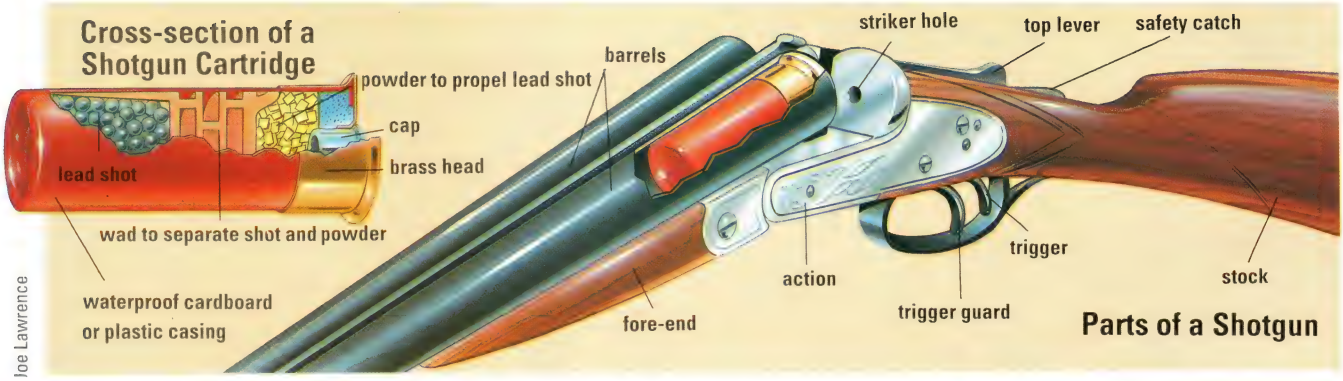
League Against Cruel Sports

Just amazing!

FIGHTING FISH

NEW ZEALANDER DONAL HEATLEY TUSSLED WITH A 6-METRE LONG BLACK MARLIN FOR OVER 32 HOURS IN 1968. THE FISH DRAGGED HIS LAUNCH 80KM BEFORE BREAKING THE LINE!

Paul Raymonde



Joe Lawrence

Jon Nicholson/Allsport

***Most shotguns** fire about 300 pellets (total 28 gm) with each shot. The range is usually not much more than 30 metres.*

Jon Nicholson/Allsport

***Game birds** are 'hung' for about a week before being eaten. Bacteria makes the flesh more tender – and smelly!*

taken through farmyards, fields and villages to accustom them to different types of animal. Young hounds that stray from the pack to chase a sheep or cat are thrashed. A hound that consistently refuses to be trained will be put down. By autumn the pack should be fit, disciplined and ready to take part in cubhunting – the hunting of young fox litters which gives the young hounds their first taste of the hunt.

Huntsmen defend their sport by pointing out that foxes are carnivorous vermin that kill chickens and lambs and worry sheep.

Pest control

This 'pest control' argument is also used to defend the hunting of hares and minks by hounds such as harriers, beagles and otterhounds.

Otter-hunting has been outlawed in Britain, where the animal is now a protected species. It has been replaced by the hunting of wild mink, a vicious animal that feeds on chicks and eggs.

Just as controversial is deer hunting, which is still carried on in many European countries. In Britain this once took the form of 'carted' staghunting, where a deer was selected from a domesticated herd – often from a private deer park – and driven to a 'meet'. The deer was then released to be chased by staghounds, followed by hunters on horseback. When the hounds caught up, they would not kill the deer but surround it and bay. The hunters would then return it. But stag hunting today usually ends with the slaughter of the deer and the distribution of its meat – venison. The hunters use a shotgun to shoot the deer at close range, killing it instantly. When a deer is tracked on foot – without the use of hounds – a high-powered rifle is used.

Grouse shooting in Scotland attracts hunters from around the world. The grouse are bred for shooting but are protected in the wild until the season opens on 12 August each year. Then shooting parties advance on the moorlands with teams of 'beaters' ahead to chase the birds into the air. The sport is similar to clay pigeon shooting - except that the targets are live.

Bob Lawrence

***Electronic 'bleepers'** attached to terriers' collars help locate them when flushing out foxes underground. The transmitters have a range of about 4.5 metres.*

DEER HUNTING

Farmers in Europe defend the hunting of wild deer because they cause damage to trees and crops. Stags grow a new set of antlers every year. As these begin to harden they irritate the animal, which then rubs them against trees. This can strip the bark off a tree so badly it can die. Wild deer also cause crop damage, eating root vegetables and flattening fields of corn.

When the numbers of deer rise to an unacceptable level, they have to be cut back (or culled) and this is where the hunters come in. They use special hounds called tufters that chase the chosen stag away from the herd to start the hunt. When the hounds catch the stag, they surround it until the hunters arrive. It is then shot and taken away to be butchered.

***In Spanish bullfights**, the kill is by the matador thrusting a sword, known as an estoque, between the bull's shoulder blades, severing the aorta.*

Vandystadt/Allsport

POWER IN MOTION

- JUMPING TECHNIQUES
- BODY TYPES
- ACCURATE MEASURING

The 'Fosbury Flop' *is a relatively simple high-jump to master because its movements in the air are 'bilateral' (arms and legs move together in the same direction).*

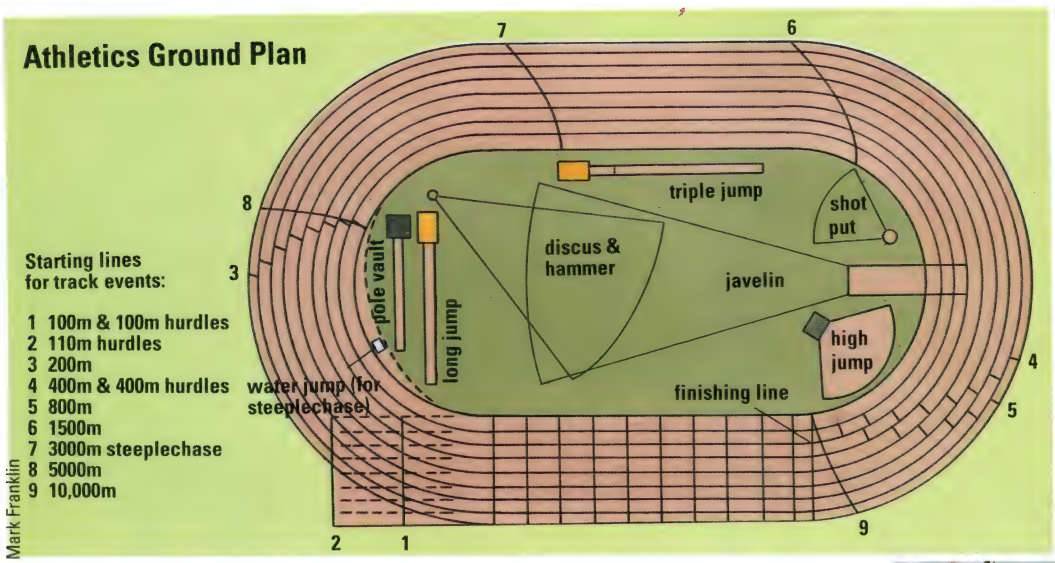
A JAVELIN ARCING 80 METRES through the air, a perfect pole vault or gravity-defying high jump – all require immense skill and athleticism.

Field athletics comprises four jumping and four throwing events. Jumping events may be divided into vertical jumps for height (high jump and pole vault) and horizontal jumps for distance (long jump and triple jump). They all follow the same pattern of run up, take-off and landing.

Gravity and ballistics

The angle and speed of take-off and the trajectory (or flight path) of the athlete are vital to the success of the jump. The trajectory is determined by the position of the body at take-off, with the crucial factor being the body's centre of gravity. This needs to be further forward when aiming for distance, and further back when trying for height. As the law of gravity is overcome, the laws of ballistics come

Supersport Photographs



Mark Franklin


Tony Duffy/Allsport

Record-breaking athlete *Jackie Joyner-Kersee of the USA launches a shot. She holds the world heptathlon record – the ladies combined event of 100 m, 200 m, 800 m, hurdles, high jump, long jump, shot and javelin.*

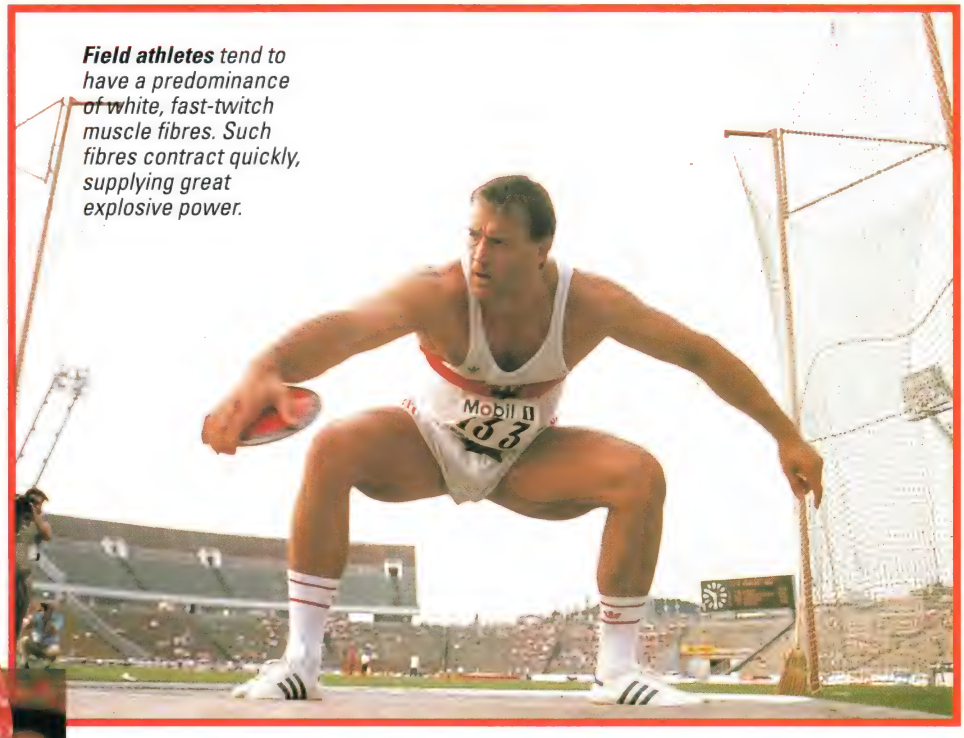
A bird's-eye view *of a typical athletics field shows the importance of scheduling the events of a big meet. Athletes, officials, support staff, television crews and reporters must all be co-ordinated.*

into effect. When jumping for distance, horizontal force is most important, whereas in high jumping, upward thrust is the main aim.

High-jump styles

There are several types of high jump, including the straddle, the Western roll and the Eastern cut-off – all of which involve clearing the bar with the body parallel to it. But the event was revolutionized in the 1960s by Dick Fosbury, who introduced the famous 'Fosbury Flop'. This involves leaping head first at the bar and twisting in mid-air, so that the front of the body faces upwards. It may sound complicated, but it has allowed men to clear a new world record of 2.43 metres, and women to clear a new world record of 2.09 metres. Pole vaulters can reach much greater heights – the world record is over 6 metres – helped by a flexible fibreglass pole, which acts as a spring.

Field athletes *tend to have a predominance of white, fast-twitch muscle fibres. Such fibres contract quickly, supplying great explosive power.*


Gray Mortimore/Allsport

Weight training*, throwing practice and short sprints are major elements in Steve Backley's year-round training programme. The UK's greatest-ever javelin thrower, Backley threw a record 85.9 metres at the World Cup in Barcelona, in 1989.*


Supersport Photographs

For long and triple jumping, maximum speed at take-off is vital. The run-up may be 50 metres long, so that the jumper can hit the take-off board at top speed. It is not surprising, therefore, that top sprinters such as Carl Lewis also make good long jumpers.

The triple jump is really a variation on the long jump, but where the athlete takes off from a board further

BREAKING POINT

David Cannon/Allsport

Traditional wooden poles for pole vaulting have been replaced with fibreglass poles that are more flexible – but they do occasionally snap under pressure. This happened to Olympic decathalon champion Daley Thompson at the 1988 Olympic Games in Seoul.

from the pit. He is then permitted to land on one foot, push off and land on the other foot before making his leap into the pit. As in the long jump, it is the first mark in the sand that is measured from take-off.

Athletic physique

For all jumping events, the athlete needs great power in the lower body and legs, plus agility, flexibility and the ability to 'spring'. Studies show that taller people tend to have greater strength potential in proportion to their size, and greater respiratory capacity. Shorter people are faster to accelerate and are better able to lift their own body weight. Most jumpers tend to be tall and long-limbed. Such a build means that the athlete's centre of gravity is higher while long limbs give extra leverage and 'spring'.

Throwers tend to be solid and heavily-muscled. Their initial force, when throwing, is achieved by the strength of the legs, which transmit energy through the body to the arms. Good musculature is absolutely essential because it gives throwers power and a solid base to work from. But this can lead some athletes to building a physique more in keeping with body building than athletics, and some are rumoured to use illegal anabolic steroids to add muscle bulk.

Throwing events are divided into heavy throws (shot and hammer) and light throws (discus and javelin). But another classification can be linear (shot and javelin) or rotational (discus and hammer). In linear events, push (or impulse) is the main force, whereas in rotary throws, pull (or centripetal) force predominates.

Parameters for distance

The velocity of a thrown object at its moment of release is the most important factor in good distance throwing but many factors affect the length of a throw:

- velocity at release
- height at release
- angle of release
- the force of gravity
- aerodynamic shape of the object
- wind speed and direction
- ground reaction force

Throwing competitors must start and finish within a designated area – a rectangle for the javelin and circles for the others. The javelin thrower will have a 30-metre run-up, while the shot-putter merely moves across a circle with a 2.14-metre diameter.

Momentum

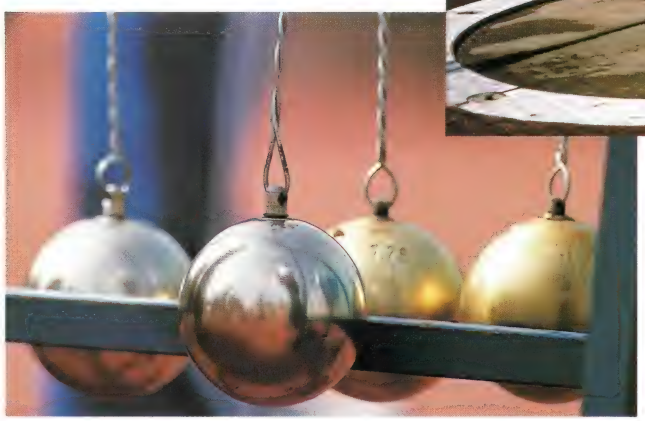
Discus and hammer throwers work from larger circles, as they need to be able to twist round as they wind up for a throw. Both start with their back to the target area and rotate through one and a half turns before launching. The hammer thrower will also swing the hammer in a circle above his head before he starts to turn, in order to gain full momentum.

Balance

Balance is of crucial importance to throwers, and is a particularly complicated matter for hammer throwers. The hammer is swung around the body to build up its speed before it is released. Because the mass of the hammer is less than the mass of the thrower, balance is maintained during these 'winds' by increasing the radius of rotation of the hammer. Thus the hammer covers a greater distance than the thrower while he spins. As the hammer gains speed the thrower uses the increasing centrifugal force to help maintain his balance. Throwing the hammer is the only field event in which women do not compete.

World records for the throws are huge distances – the men's records

Richard Francis/Action Plus



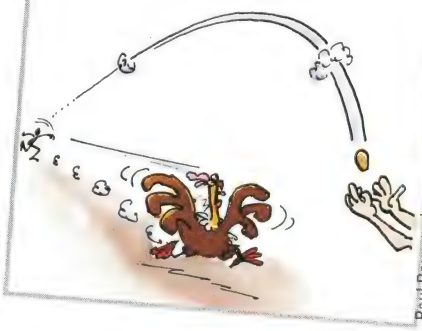
Tony Duffy/Allsport

***The body** is angled further from the vertical when releasing a hammer than for other throws. Hammers weigh 7.26 kg. The head (left) is usually of iron filled with lead.*

Just amazing!

LONG RANGE EGGS

FIELD-THROWING RECORDS CANNOT BEAT THE 96.9 METRES THAT FINLAND'S RIST ANTIKAINEN THREW A FRESH HEN'S EGG TO A FRIEND IN 1981 – WITHOUT BREAKING IT!



Paul Raymonde

for hammer, javelin and discus are all nearly 90 metres, while the women's records for discus and javelin are around 80 metres.

Traditionally, thrown distances of the shot put, hammer, discus and javelin are measured with a calibrated steel tape divided into centimetres. This is time-consuming – and inaccurate. For example, the tape may expand or contract slightly according to temperature. This will have a more noticeable effect on longer throws. Also, the ground level between the throwing circle and the hit point may not be equal.

Electronic measuring

Using an electro-optical tacheometer – a surveying instrument that rapidly measures distances – such inaccuracies can be minimized. The instrument takes measurements from a base line through the throwing circle, and from a reflector planted on the hit point by a judge. It calculates the thrown distance using the angle between the base line, the instrument itself and the hit point.

With long and triple jumps the reference points are the edge of the take-off board and, again, a reflector planted by a judge. The tacheometer calculates the distance jumped in about ten seconds, and is accurate to 5 mm. Electronic measuring is especially useful for checking pole-vault measurements. Pole-vaulting athletes may ask for the uprights to be moved forward or backward (not more than 60 cm) from the stopboard to suit his or her style. Each time the up-rights are moved or the bar is adjusted, the bar height is checked.

Television tie-up

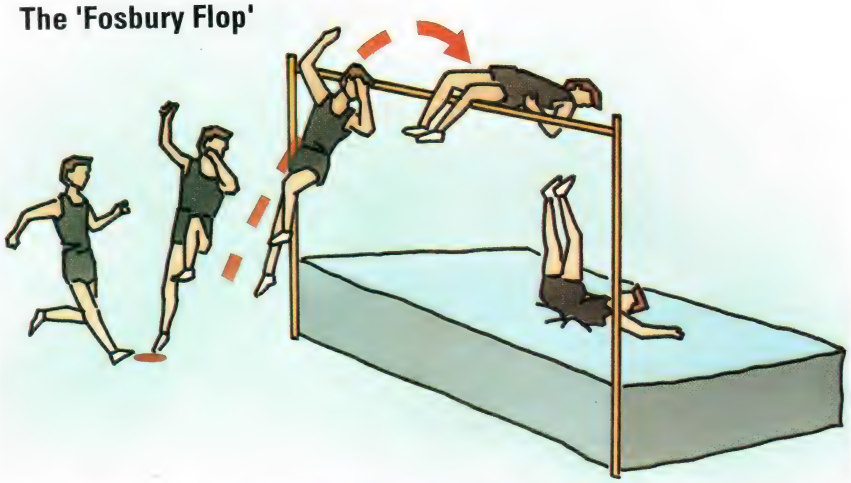
Because they are in digital form, electronic measurements can be automatically relayed to field scoreboards, central computers, printers and character generators to be turned into video signals for displaying on television.

THE LAW OF A THIRD

Women athletes often achieve their best results at an earlier age than men because their bodies mature more rapidly. The biological differences between men and women are taken into account by the International Amateur Athletic Federation. Their coaching manual suggests 'The Law of a Third' is suitable for women in training for running events:

- Reduce by one third, the total distance normally applicable to men
- Reduce by one third the number of fast intervals

The 'Fosbury Flop'

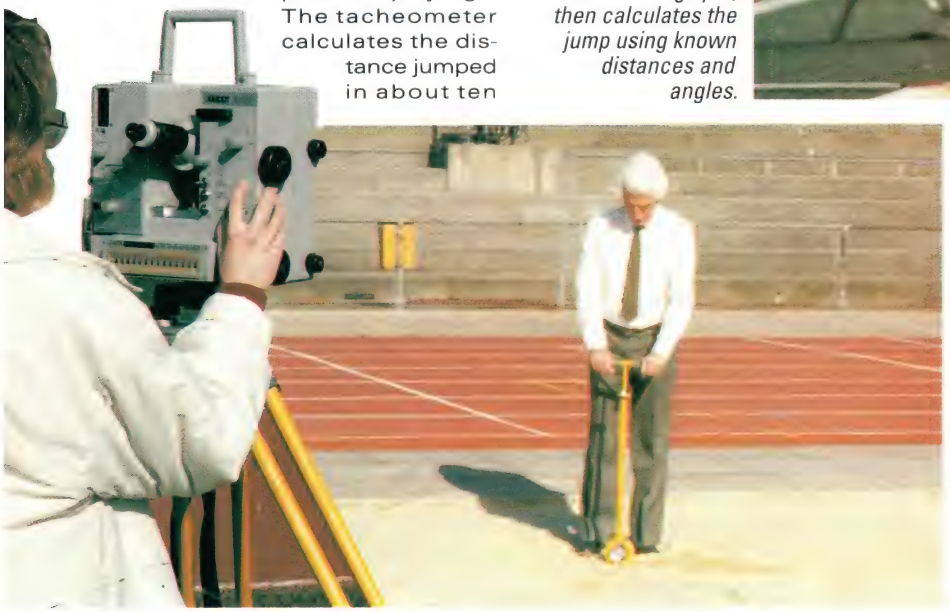


Simon Critchley

This revolutionary high-jump style *rotates the body around its own horizontal axis. The foot plant and turn stop the body's forward motion but keep it moving upwards – so the total force of the jump can be directed up into the air rather than towards the bar.*

Carl Lewis *adopts the 'hang' position during a long jump to maintain balance and prepare his landing position. The black and white marker is a reference for an electro-optical tacheometer (below). This machine takes a second reading from a reflector on the landing spot, then calculates the jump using known distances and angles.*

Leo Mason/Split Second



J N Hooker/City University

SKIN STRUCTURE INSULATION SCALY LAYERS

COVER-UP

THE VARIETY OF ANIMAL coverings is incredible: a porcupine's long spiny quills, a snail's shell and a sheep's woolly coat are only three. The main surface covering of an animal, however, is its skin.

Skin protects the organs inside the body and helps prevent disease-causing organisms from entering. In many animals it is also a sense organ. The skin of a backboned animal, for example, contains sensors that detect touch, pain, heat and cold. In animals that live on land, the skin forms a waterproof layer that keeps water out while at the same time preventing the body from drying out.

Fantastic skin

In the most advanced, warm-blooded animals – birds and mammals – it helps keep the body at an even temperature. On warm days blood vessels near the skin's surface expand and heat escapes through the skin. On cold days these blood vessels contract and slow down the cooling process by preventing blood from reaching the surface. Sweating also helps some mammals (Man, for example) to keep cool.

Insect armour

In invertebrate animals (animals without backbones) the skin is very simple, consisting of a single layer of cells. Sometimes there are additional features. The skin cells of an insect, for example, produce a hard outer layer, known as the cuticle, made of a substance called chitin. The whole structure is rigid, but elastic enough

***The red-eyed tree frog**, in the tropical rain forest of Central America, has a moist, slippery skin. A layer of mucus on the skin reduces the amount of water lost from the body.*

Ken Lucas/Planet Earth Pictures

not to break easily.

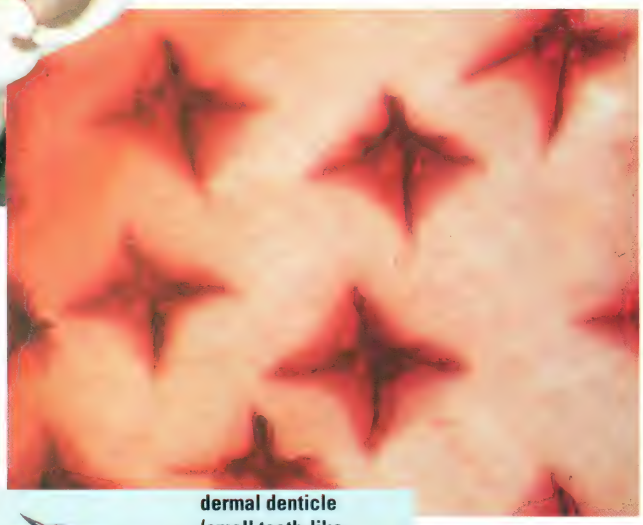
The skin of a vertebrate consists of two layers: an outer epidermis and an inner dermis, each of which is composed of several layers of cells. The epidermis is made of flat cells that are continually being renewed from below as the outer ones are rubbed off. In land animals the outer cells of the epidermis are dead and filled with a substance known as keratin. This outer layer of dead cells provides the waterproofing that is so vital to land animals. In some places it forms thickened areas of skin, such as the warts of toads and toe pads of mammals.

In many animals, the skin cells produce definite structures on the surface of skin. The scales of sharks, for instance, and bony fishes are derived from the dermis. Similarly, the scales of some lizards originate in the dermis, with a covering of horny material produced by the epidermis.

The scales of most reptiles, however, such as alligators and crocodiles, are produced entirely by the epidermis. This type of scale simply consists of a solid, flattened piece of keratin, or horn. The scales overlap and form a tough, waterproof layer on the outside of the body – something that is completely lacking in amphibians, the animal group from which reptiles evolved. Similar scales are also found on the legs of birds and on the tails of certain kinds of mammal, such as rodents.

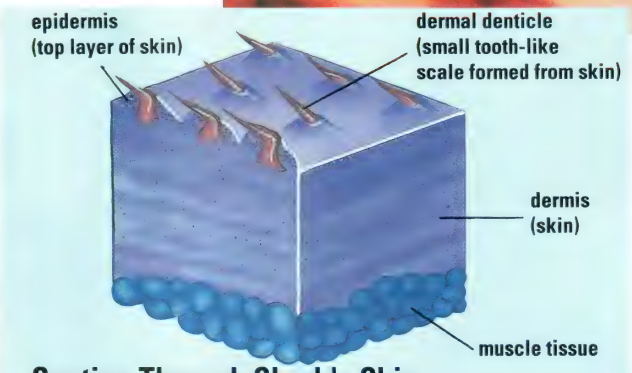
Claws are also horny structures derived from the epidermis of the skin. These structures protect the tips of the digits

A shark's teeth *are produced by the dermis (skin), as are the teeth of all animals with backbones. Each tooth has the same structure as scales on the shark's skin.*



James Bell/Science Photo Library

Shark-skin *is covered by sharp, tooth-like scales called denticles (magnified 150 times, above). Made mostly of enamel and dentine, they protect the body by acting as a kind of armour-plating.*



Section Through Shark's Skin

Mark Franklin

BLUBBER

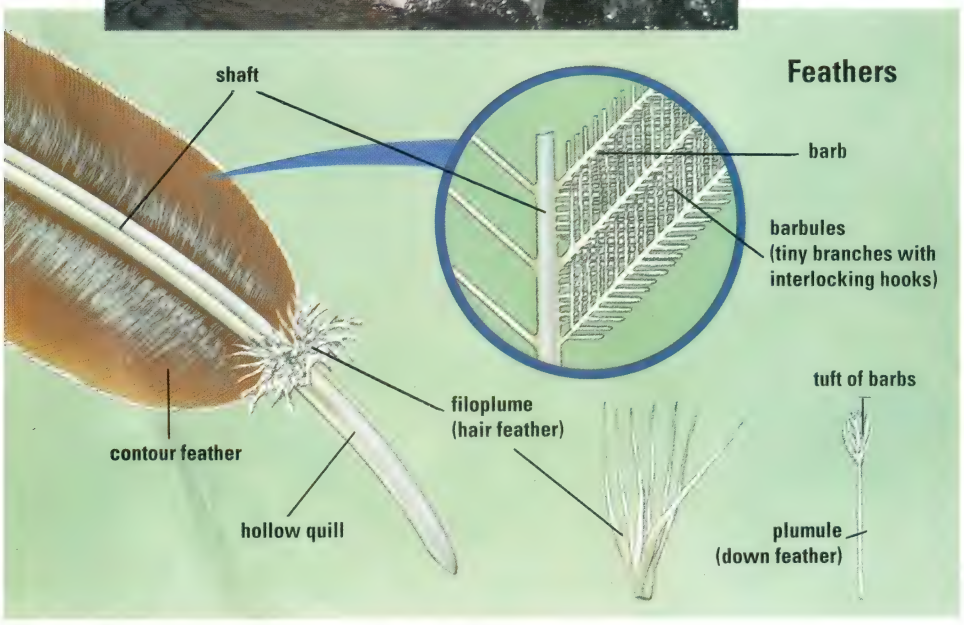
Mammals that live in very cold climates use fat to insulate their bodies and keep their precious body heat inside. A polar bear, for example, has a layer of fat under the skin, as well as a thick fur coat. For animals that spend most or all of their time in cold water, good insulation is vital. Water must be kept out of fur, as wet fur soon allows heat to escape from the body. Fur seals and sea-lions have a dense coat of waterproof fur, but they also have an insulating layer of fat, or blubber. However, in cold, wet conditions blubber is the more effective insulator. Whales, true seals and sea cows, with very little hair, rely on a thick layer of blubber under the skin to keep them warm.

Sweat glands *in the skin cool the body when it gets too hot by secreting water. The water also contains waste products, such as salt and urea.*

Vandystadt/Allsport

Dr MR Hill/Nature Photographers Ltd

The mallard drake *is insulated from the water by an undercovering of plumules, or down feathers. In addition, all adult birds have contour feathers (including flight and tail feathers) and fluffy filoplumes (below).*



reptiles. Feathers help to keep birds warm and enable them to fly. Their colour is important for display or camouflage. A bird needs to keep warm because it is warm-blooded – that is, it maintains its body temperature using heat produced by chemical reactions

MP Harris/Nature Photographers Ltd

The potential elasticity of skin *is demonstrated by the male great frigate bird, when he inflates a sac on his breast to attract a female to his nest site.*

Mark Franklin

(fingers and toes) and grow continuously from a special region of cells. In some animals, notably primates, claws are flattened into nails. In many grazing and browsing animals they have become hooves that are used for walking.

Growing horns

Some of these animals have horns, which consist of a central core of bone, surrounded by a horny sheath. True horns – those of cattle, for instance – are never shed, unlike the antlers of male deer, which are formed of bone. A young deer takes several years to develop a full set of antlers, which are shed and regrown each year.

The body of a bird is covered with feathers. These, too, are produced by the epidermis. Scientists believe that feathers evolved from the scales of reptiles. Feathers help to keep birds warm and enable them to fly. Their colour is important for display or camouflage. A bird needs to keep warm because it is warm-blooded – that is, it maintains its body temperature using heat produced by chemical reactions in its own body. Feathers make an excellent insulating material because they trap a layer of still air next to the body. In fact, feathers may well have originally evolved for this purpose. Only later did birds evolve a way of using them for flying.

A four-lined snake *sheds the horny outer covering of its skin in one piece. Overlapping scales of an Indian python (right) are made from horny keratin produced by the epidermis.*

C Mattison/Natural Science Photos

Mammals are also warm-blooded and must keep warm. In this case it is hair, or fur, that provides the insulation; many hairs together, like feathers, trap a layer of still air next to the skin. Hairs, too, are produced by cells that form part of the epidermis. Made of keratin, they develop in deep pits, known as follicles, that lie buried in the dermis. Each hair follicle has a sebaceous gland, which produces an

Dr Morley Read/Science Photo Library

SC Bisserot/Nature Photographers Ltd

***Bony fish**, such as the queen angel fish found in the Caribbean Sea, are covered with scales produced by the dermis, or skin. Those shown below (magnified three times) belong to the rainbow trout. Tiny crystals and pigment cells in the skin give the fish their colour.*

Mark Mattock/Planet Earth Pictures

oily substance that keeps the surface of the skin supple.

Unlike feathers, hairs are not thought to have evolved from scales. In fact, hairs probably evolved before the reptile ancestors of mammals lost their scales, and there were probably some creatures that had scales with hairs growing in between them.

Hairy monsters

Today, mammals that use fur for insulation generally have two layers of hair. The inner layer is formed from a dense mat of fine hairs and provides most of the insulation. The outer layer is made up of thicker, longer hairs that are well supplied with oil and form a waterproof covering. This is vital for many animals as, if the inner layer gets wet, it loses its insulating properties and the animal may rapidly become too cold.

Hugo van Lawick/Nature Photographers Ltd

***A Cape pangolin** in Tanzania, Africa. Its horny, overlapping scales are formed from fused hairs. The pangolin is the only mammal covered with scales.*

The musk ox is well protected from the cold of North America's Arctic tundra by its two layers of hair. A shaggy outer coat of coarse hair with strands up to 62 cm long covers a fine underfur.

Little and large

Not all animals use hair to keep warm. Elephants, rhinoceroses and hippopotamuses, for example, have a very sparse covering of hair. Such animals stay warm because they live in warm areas of the world, and because they have large bodies with thick skins. A large animal has a small area of body surface compared to its volume and loses relatively little of its body heat.

A smaller animal has a greater surface area in relation to its volume. It therefore loses more heat; because of this, most medium-sized mammals are well-covered with hair. A very small animal, such as a shrew, loses a great deal of heat.

But there is, of course, a limit to the thickness of hair such an animal can carry. The shrew maintains its body temperature by eating the equivalent of three-quarters of its own body weight each day.

Hair may be used for other purposes. A rhinoceros horn is not in fact a horn at all. It is a mass of hair-like structures fused together. Rhinoceroses in Africa and tropical Asia have been brought to the point of extinction by hunters seeking their horns. The horns are mostly used to make dagger handles. In addition, many people believe (wrongly) that ground rhino horn is an aphrodisiac and has medicinal properties.

RECYCLING SKIN

British Leather Co Ltd

Shoes, gloves, coats, saddles, luggage and chairs may all be made out of leather – the specially treated skins of animals such as pigs, goats, sheep, and especially cattle. A great deal of leather comes from cattle that have been slaughtered for meat. The skin is first stripped of its hair and cleaned. Its upper layer, or epidermis, may then be removed. Some skins are split into two or more thicknesses. Next, the hides are treated with chemicals to prevent them rotting – a process known as tanning. In one tanning process hides are soaked in a solution containing tannin, which is obtained from the bark, leaves or nuts of certain trees, such as the oak or quebracho (a hardwood from tropical America). Fats and oils make the hides supple. The hide is then shaved to the required thickness (shown above) and dyed.

Paul Raymonde

SURVIVAL STRATEGY

Michael Fogden/Oxford Scientific Films

Disguise as a leaf *is a common protective strategy in insects. This longhorn grasshopper is popularly called a katydid, after the male mating call.*

These snake eyes *are just a disguise – for the tail of the hawk moth caterpillar mimics the head of a snake, so that a predator, such as a bird, will think twice before striking.*

DECEPTION IS A VITAL tactic used by both predators and prey in the battle for survival. Many animals deceive others into believing either that they are not there, or that they are something else, or even that they are dead.

The most common form of deception is camouflage. By blending into its surroundings an animal can become part of the landscape – virtually invisible. Many tiny, transparent sea animals, for example, are nearly impossible to see – predators literally look straight through them. Fish, too, are difficult to spot in the water. Dark backs hide them from predators above and their white bellies and silvery sides blend in with bright light from the surface when viewed from below. Flat fish, such as skates

Mantis Wildlife Films Oxford Scientific Films

Tiger Camouflage

Simon Critchley

The tiger's stripes *run vertically up and down its body, so that it merges into the jungle when stalking prey. Horizontal stripes would make the tiger stand out.*

A crocodile fish, *camouflaged against the floor of the Red Sea, lies in wait for prey fish to swim by. If trodden on by a human being, its poisonous spines inflict a painful wound.*

Dr George Gornacz/Science Photo Library

PLAYING DEAD

Jane Burton/Bruce Coleman Ltd

When in a life-threatening situation, certain species may feign death by suddenly going limp and rolling over with tongue hanging out. This appears to be an instinctive, nervous reaction. It is probably not always effective, as there are many predators that happily eat carrion. Mammals known to 'play possum' in this way include opossums, foxes and African ground squirrels. Several kinds of snake also 'play dead', including the European grass snake (above) and most American hog-nosed snakes. If picked up and turned over, a hog-nosed snake rapidly flips over again, apparently under the impression that this is the most convincing position for a dead snake.

Predatory insects also use camouflage. A praying mantis, coloured green or mottled brown, sits motionless on a leaf or twig waiting for a prey animal to come within reach. A few mantises are brightly coloured, resembling tropical flowers. Such 'flowers' appear uninteresting to predators and harmless to potential prey. Crab spiders use similar camouflage colours: brightly coloured spiders sit inside flowers, lying in wait for visiting insects.

It is often difficult to pick out amphibians and reptiles from their surroundings. A brown toad, for instance, is hard to see against the ground. The long-nosed tree snake, coloured green, can easily be mistaken for a stem or vine tendril, as it lies in wait for prey.

Many animals avoid being eaten by pretending to be something that they are not. They mimic, or copy, the forms of other natural objects so realistically that they are completely overlooked by predators.

and plaice, hide on the bottom, merging with the mud, sand, pebbles or rock on which they rest. A stonefish looks exactly like a stone.

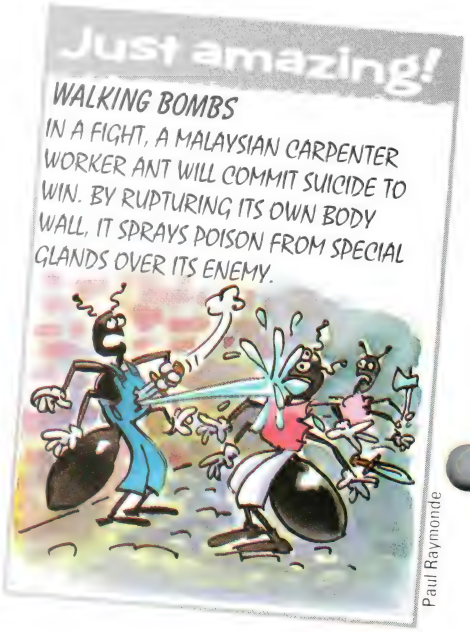
Land animals may have colourings that make them less easy to spot while they are still. This is particularly important for very young animals: a young fawn, for example, is well camouflaged as long as it lies motionless in the grass. The stripes of a zebra break up its outline and blend with patterns of light and shade. They also make individuals difficult to pick out from the herd.

Almost undetectable

Many birds use camouflage to avoid being caught. Nesting birds are particularly vulnerable and for this reason females are often less brightly coloured than the males. Ground-nesting birds, such as partridges and pheasants, have a mottled appearance that makes them almost undetectable if they keep still. The ptarmigan and willow grouse have white plumage in winter. An alarmed bittern sits with neck outstretched and sways from side to side. This makes it nearly impossible to see among the reeds in which it nests.

Insect subterfuge

Camouflage is also a common form of defence among insects. Beetles, caterpillars and moths usually have green or brown colorations that enable them to rest on trees and other plants without being easily seen. Patterns on the wings of some moths are arranged in such a way that they match the pattern of tree bark or lichen in the background.



Paul Raymonde

Insects are particularly good at this. Stick insects resemble twigs or pieces of grass and there are several kinds of caterpillar that rest on branches in such a way as to look exactly like short twigs. A number of insects are disguised as dead or living leaves, often complete with blemishes and 'chewed' edges. Tree hoppers, for instance, resemble thorns. When curled up, some caterpillars look just like bird droppings, so that birds in search of a meal will naturally leave them alone.

Warning colours

Poisonous animals often have bright colours, warning predators to avoid them. A wasp's black and yellow colours are a typical example. Warning colours have been copied by many harmless animals, so that predators should be fooled into thinking them inedible. Birds tend to avoid non-poisonous hoverflies simply because they have black and yellow markings. The red, black and yellow markings of deadly poisonous coral snakes are mimicked by non-poisonous milk snakes and kingsnakes, so that it is difficult for predators to tell them apart.

Eye-spots

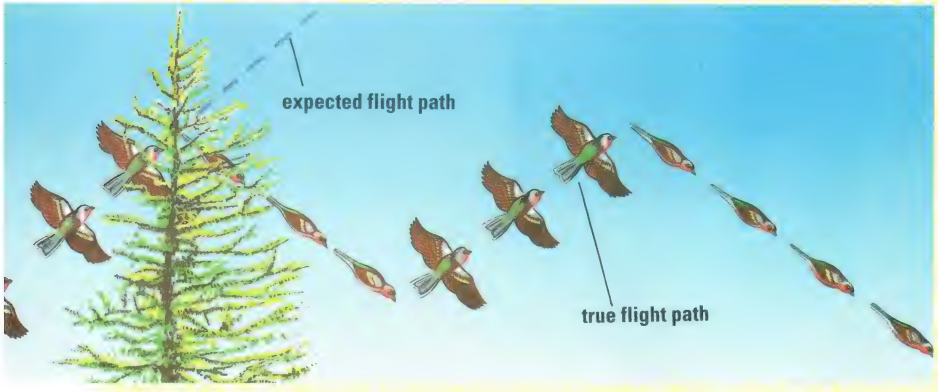
When in danger, some animals may try to bluff their way out of trouble. Several kinds of butterfly and moth have wing patterns that look like staring eyes. If a predator approaches, the insect will suddenly expose its eye-spots – making the startled predator think that it is face to face with a large animal. Before it can recover, the butterfly or moth has escaped. There is a large species of South American frog that, when threatened, displays a pair of huge eye-spots on its rump.

False heads

Some species of butterfly give the impression of having a head (complete with compound eyes and antennae) at the tip of their hindwings when the wings are closed. A predator launches an attack at what it thinks is the head of the insect, only to discover its mistake when the butterfly flies off.

A number of caterpillars, too, have false eyes. Many hawk moth caterpillars can change the shape of their front end, creating a large false head just behind the (smaller) real one. When threatened, the caterpillar threshes the false head from side to side. This gives a predator the impression that it is attacking a snake and may well frighten it away.

DECEPTION TACTICS OF THE CHAFFINCH



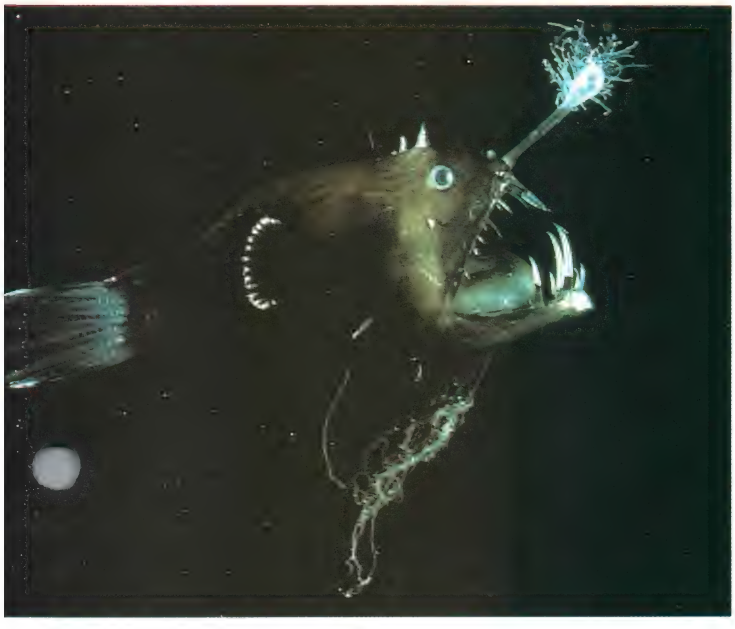
Simon Critchley

The chaffinch has a flight pattern that makes it difficult for a predator (often a hawk) to predict where it will next be. Flying up into the air, the bird flashes easily seen white patches on its wings and tail. Suddenly it dives, with wings closed and white flashes concealed. To an observer following the line of flight, the bird seems to have disappeared. When the bird changes its direction behind a tree, this strategy is particularly effective. After diving, the chaffinch climbs again, opening out its wings and displaying its white flashes – but at a quite different point in the sky to where a predator might have expected.

Astrid & Hanns-Frieder Michler/SPL

The harmless hoverfly *has similar markings to a wasp or bee, so predators (such as birds and toads) tend to avoid it.*

M P Kahl/Bruce Coleman Ltd



Peter David/Planet Earth Pictures

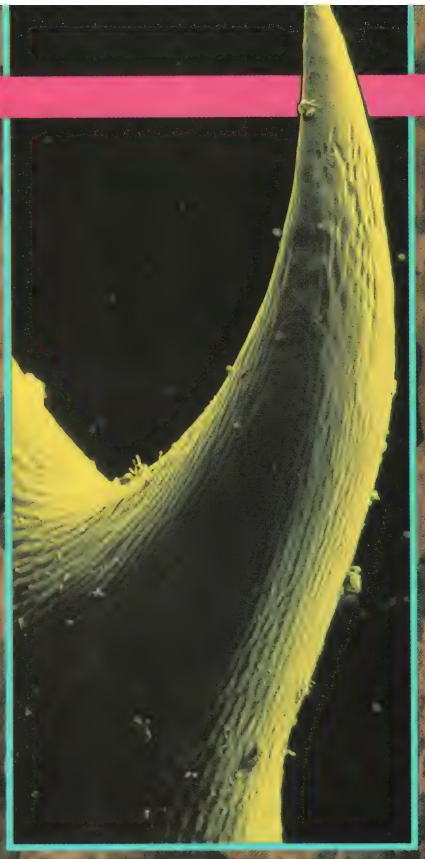
Two heads *are better than one for the shingleback lizard from Australia. Predators are posed the problem: which head is the real one and which is actually the tail?*

A luminous lure *dangles just in front of the mouth of the deep-sea angler fish, looking like a morsel of food. Any small fish that is tricked into coming too close as it investigates the bait is quickly snapped up.*

A mosquito larva (called a wriggler) is digested by a bladderwort. The larva is trapped in one of the plant's hollow 'bladders' by a trapdoor that snaps shut on its victim.

Hair on a stinging nettle leaf, magnified 200 times. When skin brushes against such a hair, the tip breaks off and injects the skin with toxic substances.

G I Bernard/Oxford Scientific Films



Dr Jeremy Burgess/Science Photo Library

The rose protects itself with thorns (this one magnified 114 times) that project from the plant's stems. Each thorn is actually an adapted hair.

R B Taylor/Science Photo Library

The bull's horn acacia of Central America feeds ants with nectar secreted from the base of its leaves and also provides nesting-places for them, inside long thorns. In return, the ants protect the tree by driving away other insects, removing fungi from leaves and destroying other plants that grow too close.

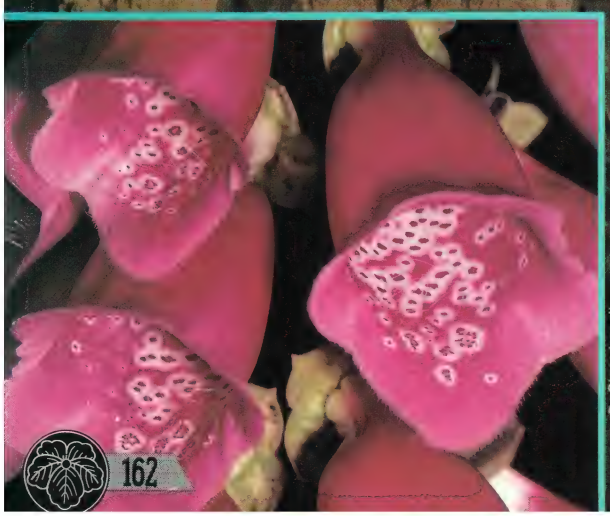
Philip Sharpe/Oxford Scientific Films

Insects stuck on the sticky leaves of a butterwort are absorbed by the plant as their bodies disintegrate under the action of digestive enzymes.

The foxglove may look beautiful, but it contains a drug, digitalis, that is poisonous if too much is eaten.

Wayne Hams/Planet Earth Pictures

J L Mason/Ardea London

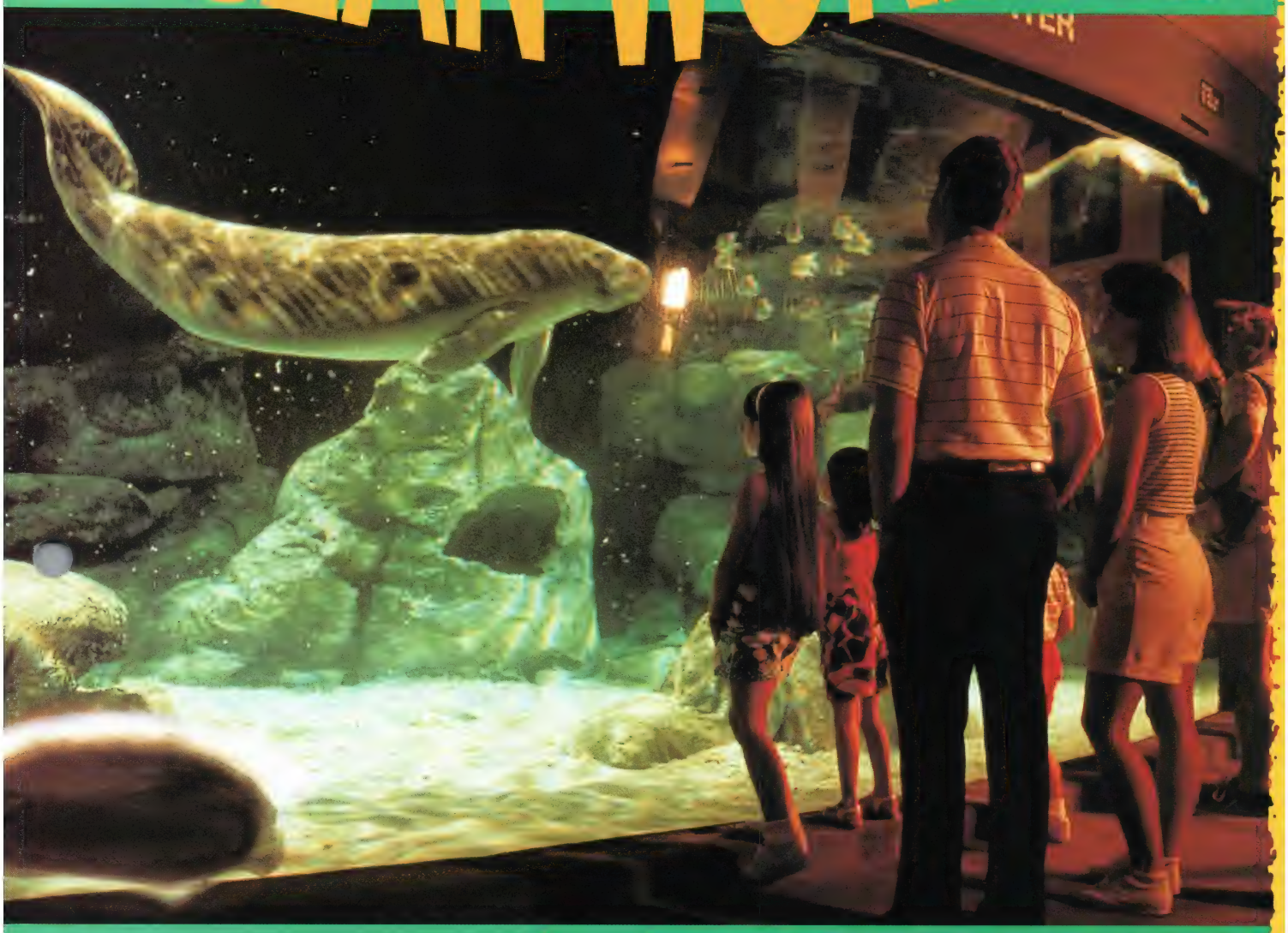


Dr Chris Lovell

Deadly stinging nettle Urtica ferox, found in New Zealand, has killed children – and even horses – who have fallen into clumps of the plant.

Q DOLPHINARIUMS Q SALT EROSION Q WATER FILTERS

OCEAN WORLDS



THE WONDER OF WITNESSING sea creatures in their 'natural' environments thrills thousands of visitors to oceanaria each year. The planning and work involved behind the scenes of these ocean worlds is almost as impressive.

Brookfield Zoo in Chicago had many problems to overcome when building its new Seven Seas Dolphinarium – not least of which was recreating a salt water environment thousands of kilometres inland.

Water of life

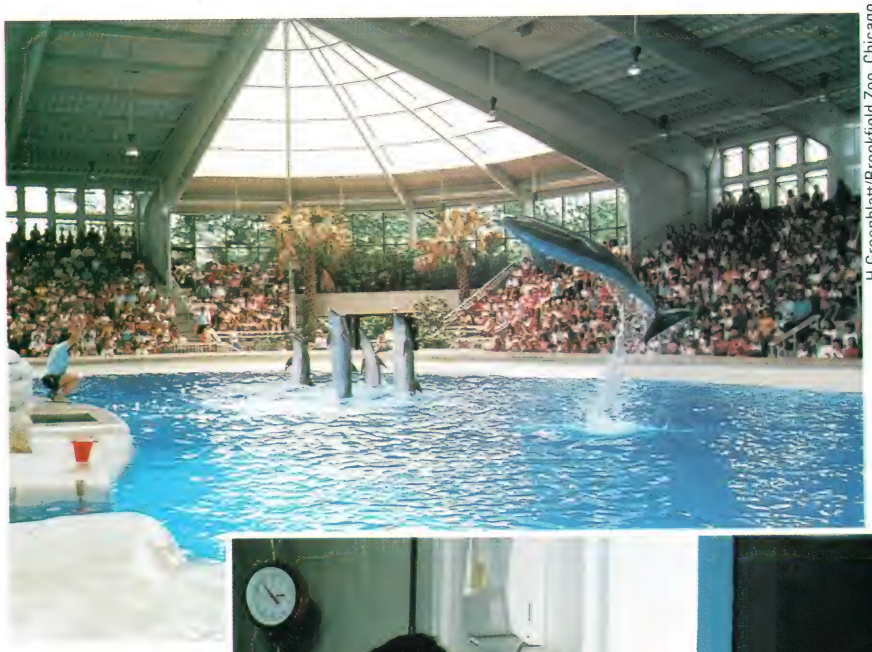
When seawater cannot be pumped into an oceanarium, it has to be prepared from fresh water mixed with the same balance of salts and minerals normally found in the ocean.

Land and sea creatures *confront each other at 'The Living Seas' exhibit at Walt Disney's EPCOT Centre in Florida – the world's largest oceanarium.*

Studies of emperor penguins *in captivity show that they distinguish each other by slight variations in the timing, tone and pitch of their calls. Each bird's call has been found to be unique.*

CRAB MIGRATION

At the National Museum of Natural History in Washington, scientists have set up a mini ecosystem based on nearby Chesapeake Bay. The ecosystem is 15 metres long and consists of eight interconnected tanks. At one end, a trickle of fresh water represents water entering the Bay from the Susquehanna River. This feeds downstream into various tanks containing samples from appropriate parts of the real bay together with progressively saltier water. Computers control light levels to simulate night and day and to trigger the ebb and flow of miniature tides. Pre-programmed seasonal variations of daylight are proving so accurate that the population of blue crabs in the model bay migrate just as they would in the real Chesapeake.



H Greenblatt/Brookfield Zoo, Chicago

Individual dietary attention *ensures the well-being of dolphins at Brookfield Zoo, Chicago. Their performing pool (above) is 7.6 metres deep and holds over 3 million litres of salt water. The ceiling is designed to take account of the fact that dolphins can jump six metres above the water.*

About three-quarters of the dissolved chemicals in seawater is ordinary salt, or sodium chloride. Other minerals, such as sodium iodide and potassium chloride, are vital to the well-being of marine life.

Design considerations

At Brookfield, the dolphinarium is enclosed because of harsh Chicago winters. The building is designed to withstand the eroding effects of the salty atmosphere. Salt destroys metal and so metal supports for the structural concrete were coated with epoxy resin. Concrete was mixed with a salt-resistant additive normally used in concrete for road building.

The well-being of the animals is of chief importance and their surroundings are constantly monitored. Water is tested for pH, salt content, oxygen content, chlorine, ammonia, bacteria, temperature and hardness, and is adjusted accordingly. A chemistry laboratory is required to cope with this work. In caring for dolphins a kitchen area is also needed in which to prepare fish. And holding pools – away from the performing pool – where dolphins can rest or be quarantined when sick.

Mike Greer/Brookfield Zoo, Chicago

Cleaning oceanaria is more complicated than cleaning swimming pools. Swimming pools can be 'shock chlorinated' to kill bacteria and algae. The same treatment in oceanaria would harm sea creatures.

Waste disposal

Water is kept clean by continuous filtering through sand and gravel filters. Controlled chlorination acts as a disinfectant. The water is also treated with ozone to deal with organic waste that is too small to be filtered. This last process is important considering one dolphin can produce about 10 kg of organic waste each day.

Adult killer whales are the largest sea mammals in captivity. They are, like dolphins, highly intelligent creatures that can learn to perform elaborate stunts. After initial training with a target on a pole, the animals learn to respond to a variety of hand signals and whistle sounds. Dolphins, whales and seals can be taught to leap, balance objects, give rides to human trainers and make a wide range of vocalizations.

H Greenblatt/Brookfield Zoo, Chicago

Computers *control filtering systems and water temperatures at oceanaria, but elbow grease still works best to remove algae from viewing windows.*

Paul Raymonde

Q ODDS Q 'SYSTEMS' Q ROULETTE

THE NUMBERS GAME

The casinos *of Las Vegas are paid for by the small advantage the house has built into games of chance. In the US, casinos use a roulette wheel (below) with a zero and a double zero, ensuring a profit of 5.26 per cent in the long run. European roulette wheels have only a zero, giving casinos a built in advantage of just 2.7 per cent.*

Spectrum Colour Library

THROW A DICE, DEAL A CARD from a well shuffled pack, spin a roulette wheel – these are all ways of throwing up a completely random number. Yet though the results are quite unpredictable, they are still ruled by the laws of chance.

The chances of throwing a two, for example, when you roll a dice are one in six. This just means that in a very large number of throws, approximately one sixth will be twos. A dice can show six different numbers, and if it is thrown fairly, it will come up with each about the same number of times in the long run.

Chances and odds

We also say the odds are 'five to one against' throwing a two, meaning that in the long run other numbers will occur five times as often as a two.

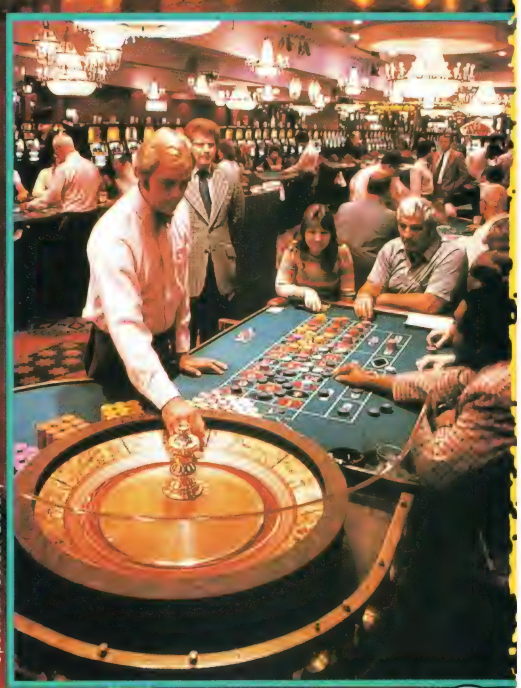
If you bet on rolling a two at odds of five to one, you will get winnings of five times your stake if your two comes up (plus your stake back). In the long run your winnings will probably balance your losses.

But with organized gambling – in a casino or at a horse-track – you can confidently expect to be out of pocket in the long run. What you pay in stakes and entry charges, if any, minus your winnings, has to cover the organizers' costs, staff salaries, overheads and profits.

Fair odds

In some cases, the law requires that winnings be paid out at fair odds, and the organizers' income comes only from the gamblers' entry charges. But usually their income comes from paying out at odds that are slightly loaded against the gambler.

For example, in roulette you bet on whether a particular number or combination of numbers comes up. The numbers in the game run from 1 to



Spectrum Colour Library

36, together with zero and sometimes double zero. Assuming there is a double zero, then a bet on a single number will win on average one time in 38. You can expect to come out at level over a long period if you are paid at the rate of 37 to one. In fact, bets are paid off at 35 to one – as if there were only 36 numbers altogether.

Beating the house

The world's casinos and race tracks are filled with people convinced they can beat the odds with some 'system'. The simplest is called the *martingale* and can be applied in any sort of gambling. All the gambler has to do is, after any loss, stake a sufficient amount to ensure that a win next time will pay off the losses so far and provide some profit. If there is a run of losses, the gambler must sit tight and bet more and more until he wins – which must happen sooner or later.

This system fails because there is often a limit to the stakes you are allowed to bet, or if there is not, the gambler runs out of money. On a losing streak he will not be able to stake enough to provide winnings to pay off the losses already accumulated.

Many gamblers are taken in by what is known as the *Monte Carlo fallacy*. If, say, an even number comes up ten times in a row at roulette, they would bet that the next number will be odd. In fact, if the wheel is fair, the chance of an odd number coming up is still the same. The chance of any number coming up – even or odd – is not influenced by the numbers that have come up before it.

The dice game *Craps is popular in the US. Two dice are rolled and bets are placed. Despite players' claims to skill, the results are random, though in a casino, the house takes an advantage of between 0.6 and 27 per cent over fair odds, depending on the size of the bet.*

Tony Stone Photo Library, London

Tony Stone Photo Library, London

Jon Nicholson/Allsport

Element of skill

Some games combine an element of skill with the element of chance. Poker is one of these. In the long run the good and bad luck that comes from the deal of the cards averages out and the player's skill asserts itself. Some poker players are able to make a living, financed by less skilful players.

In horse racing too, there is a tiny minority of professional punters who make a living at it. One even devised a mathematical system which indicated the horses' chances of winning. After making millions with this system, he went on to publish form books – giving others the benefit of his expertise.

In racing, *the outcome is not just a matter of chance – it depends on the jockey and the horse. The odds are fixed by the money bet.*

SETTING THE ODDS

In games of pure chance like roulette, the odds are fixed by the mathematics of the situation. But in less clear-cut events like horse racing, odds have to be arrived at by a longer process. Bookmakers hire experts who assess each horse's form and come up with an initial list of odds. As money is placed on each horse, the odds are adjusted accordingly. Large bookmakers will take bets on almost anything. One offers:

- 500 to 1 against the British government recognising the existence of flying saucers
- 10,000 to 1 against President Bush announcing that he has met an alien from another planet
- 500 to 1 against Elvis Presley being proved to be still alive
- 100 to 1 against London's Natural History Museum recognizing a previously unknown creature as responsible for the Loch Ness monster sightings. In 1983, the odds briefly fell to 25 to 1 following new evidence for 'Nessie'.

Paul Raymonde

SHAPES IN NATURE

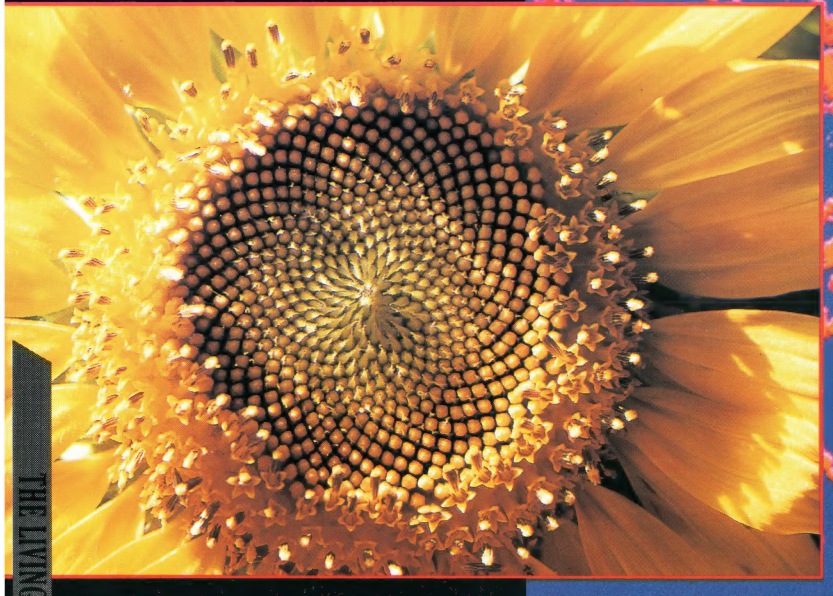
Q SYMMETRY Q THE FIBONACCI SERIES Q SPIRALS

MANY STRUCTURES AND patterns recur again and again in the natural world. Very often, their size and shape have not developed at random, but have built up according to strict mathematical rules.

Spirals are found everywhere – in shells, in sunflowers, in pine cones and even in galaxies, such as our own Milky Way. The most common type of spiral traces the path of a point as it rotates around a central point or line, the point gradually moving outwards from the centre. This is called an equiangular spiral, because a line drawn from the centre will cross each coil at the same angle. It is also known as the Golden Spiral.

The shell of the pearly nautilus (a

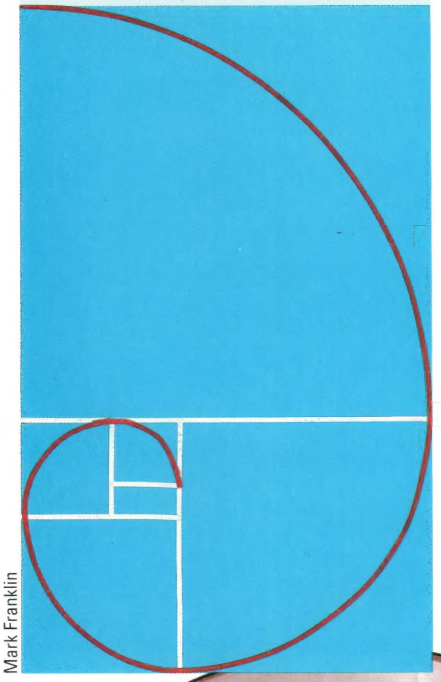
James Robinson/Oxford Scientific Films



NOAA/Science Photo Library

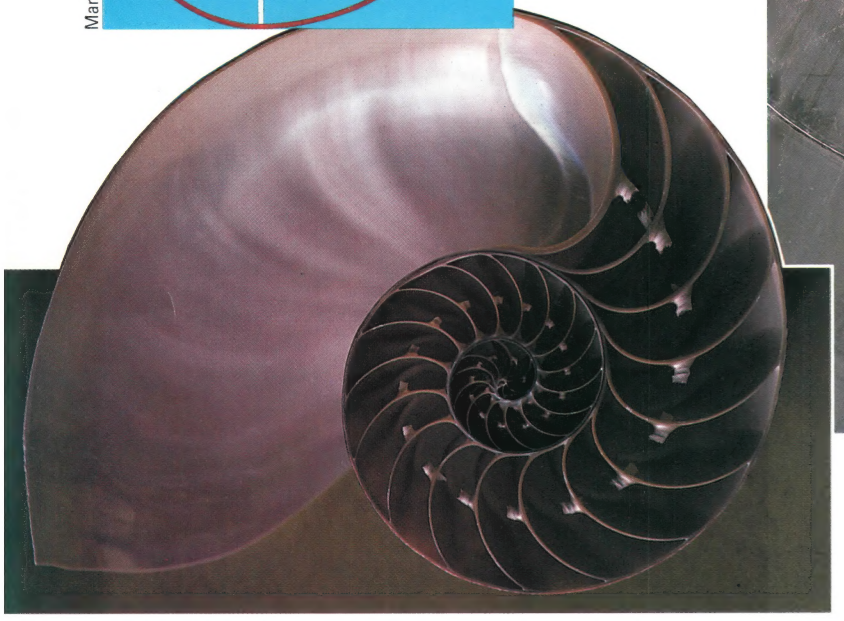
A storm twists in a spiral *over the Bering Sea in the far north of the Pacific. On quite a different scale, florets spiral outwards (above) from the centre of the head of a sunflower.*

The Golden Spiral



Mark Franklin

***A Golden Rectangle** can be divided by a single line into two parts: one a square; one a smaller Golden Rectangle. To form the graceful curve known as the Golden Spiral. Golden Rectangles are nested inside one another and a curved line drawn as in the diagram.*



ZEFA

***The equi-angular spiral,** or Golden Spiral, is found in the natural world in many forms, including the shell of the pearly nautilus (a type of mollusc).*

Daudier/Jerrican

***A screw** is a wedge cut into the form of a helix – a spiral shaped like a coiled spring. The helix is the most common shape in the natural world, present as the DNA in every living cell.*

mollusc found in tropical regions of the Pacific Ocean) is a spiral of this type. It consists of a series of chambers, each of which housed the nautilus's soft body until the animal grew too large and it made another chamber for itself.

In the 13th century, an Italian mathematician called Fibonacci studied a series of numbers now named after him. The series begins: 1, 1, 2, 3, 5, 8, 13, 21, 34 and continues into infinity. Each number (after the first two) is the sum of the two preceding numbers. The individual numbers in the Fibonacci series occur in nature in many different forms.

Twists and turns

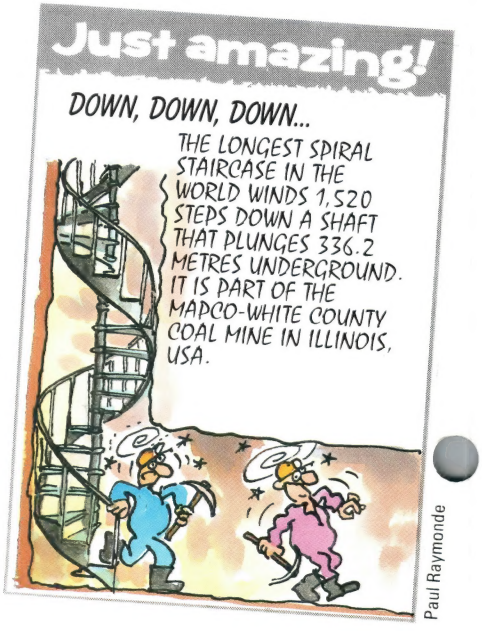
On a sunflower head, for example, you will see spirals, some turning clockwise and some anti-clockwise. (The spirals are made up of hundreds of tiny flowers called florets.) Typically, there may be 21 spirals turning in one direction and 34 in the other – two successive numbers in the Fibonacci series. The numbers of left and right-handed spirals in a fir cone are often from the series – 8 and 13 are typical examples.

The shoots on many types of leaf stem branch off at points that form a spiral around the stem. In oak and fruit trees the shoots occur every two-fifths of a turn round the main stem; in poplar and rose, every three-eighths of a turn; in willow and almond at every five-thirteenths of a turn – the numbers appearing in these fractions all coming from the series. The Fibonacci series cannot be explained, only observed.

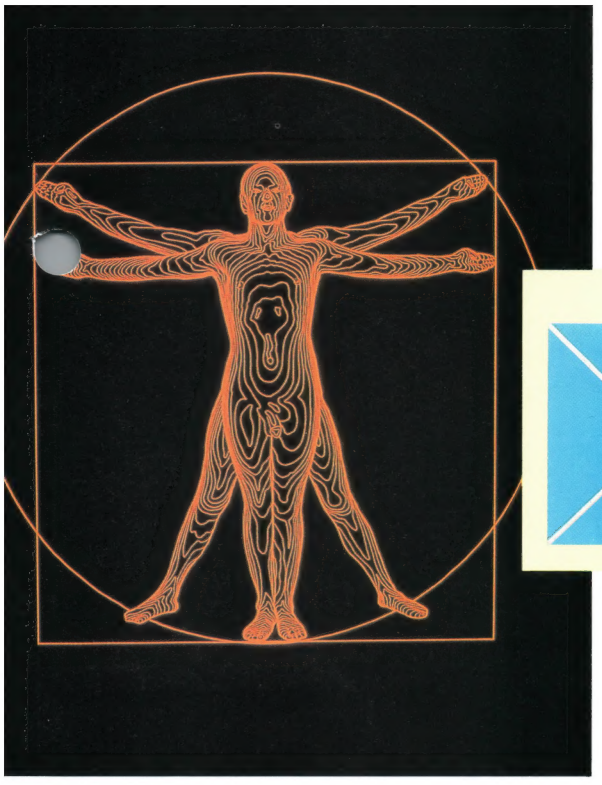
When examining how many things, both living and inanimate, are

PERFECT HARMONY

The power of numbers is present everywhere – even, surprisingly, in the creation of music. Suppose a guitarist plays several notes successsively on a single string. First he plays the 'open' (unfingered) string. Then he slides a finger along the fretboard to alter the length of the string that vibrates. Harmonious (sweet-sounding) notes are produced when the string is fouth-fifths or three-quarters or two-thirds as long as its full length (and at certain other positions). The same ratios apply to lengths of organ pipes, or the different lengths of the air paths created by pressing the keys of a valve trumpet.



Paul Raymonde

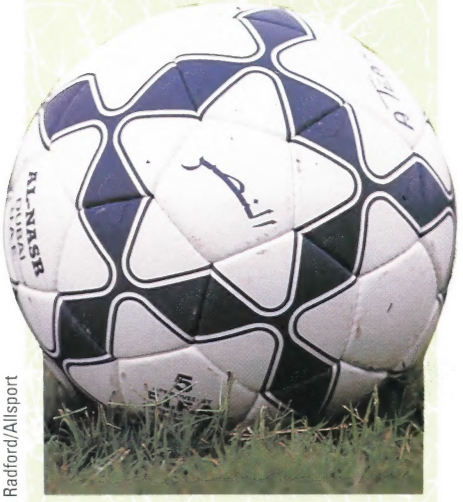


Dr Robin Williams/SPL

***A contour map** of the body from a drawing by the Italian artist Leonardo da Vinci (1452-1519), illustrating the concept that proportion is fundamental to the human form.*

FOOTBALL ENIGMA

How can a football manufacturer make a ball from flat pieces of leather? It looks at first glance as if its surface consists of hexagons (six-sided figures). If you look closer, however, you will see that there are 20 hexagons (which, on their own can only form a flat surface) and 12 five-sided pentagons. This so-called *pentagonal dodecahedron* is a structure found in many places in the natural world. The outer coating

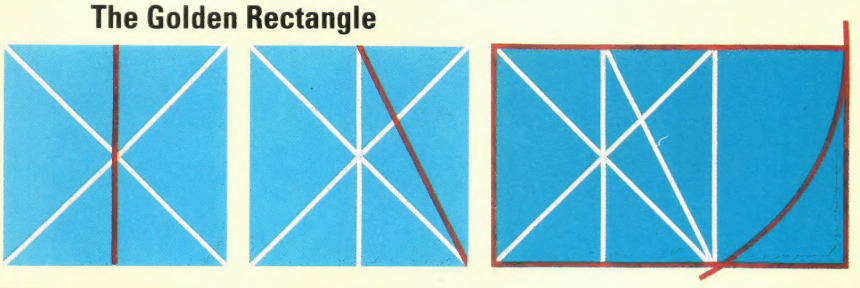


Ben Radford/Allsport

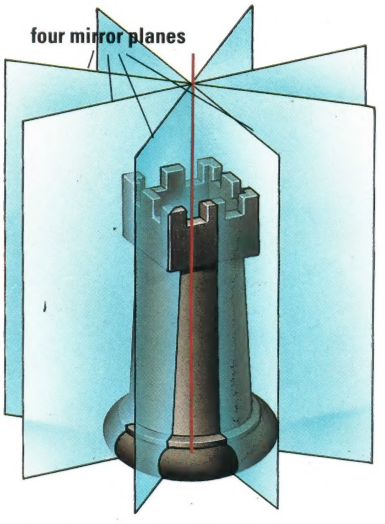
of many of the viruses that attack plants and animals are constructed around this arrangement. Similarly, a tiny single-cell life form called a radiolarion is covered with a kind of 'net bag' of hexagons and pentagons, which forms its external skeleton.

***To construct a Golden Rectangle,** divide a square into two identical rectangles (left), draw a diagonal in one rectangle (centre), then extend the short side of that rectangle to the same length as the diagonal line (right).*

The Golden Rectangle

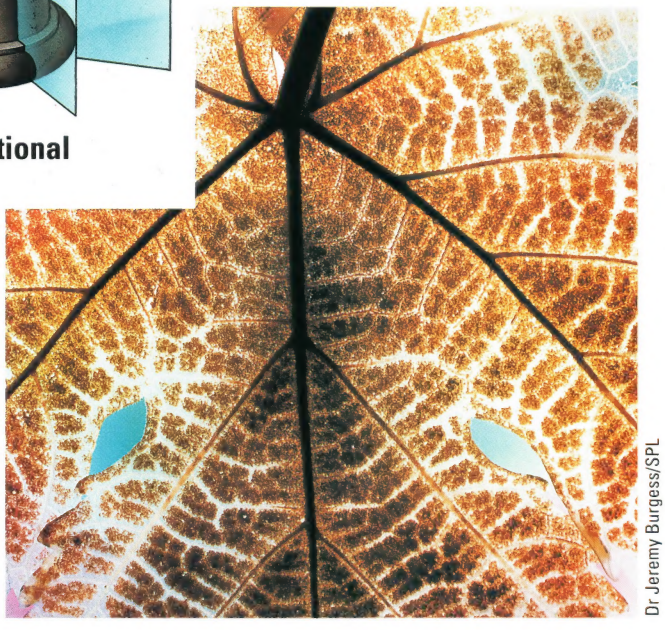


***This chess piece** has rotational symmetry. When rotated 90°, it looks as it did before it was moved. This can be done four times – then it is back in its original position. So the piece has fourfold rotational symmetry.*



Fourfold Rotational Symmetry

***Reflectional** symmetry is shown by this leaf from a grape vine. The right side of the leaf is a virtual mirror image of the left . An example in the animal world are the wings of a butterfly and in engineering, the spans of a bridge.*



Dr Jeremy Burgess/SPL

of symmetry, consider a five-pointed star. If you rotate it through a fifth of a turn, it will look exactly the same as before – it has a fivefold rotational symmetry. A six-pointed star has twofold, threefold and sixfold rotational symmetry; it can be turned halfway, or given a third or a sixth of a turn, and still look the same. The shape with the highest possible symmetry is the sphere – however it is twisted, it always looks the same. The starfish is a rare example of an animal with high rotational symmetry (fivefold).

Mark Franklin

Mirror image

The head of a daisy has rotational symmetry. A butterfly, on the other hand, has reflectional symmetry. If the left half of a butterfly is reflected in a mirror, the reflection is almost identical to the right half of the insect. Many plants, orchids for example, have reflectional symmetry and so do many animals, including humans. Or rather, the human body is symmetrical externally. Our internal organs are not symmetrical – the stomach, for example, is on the left side.

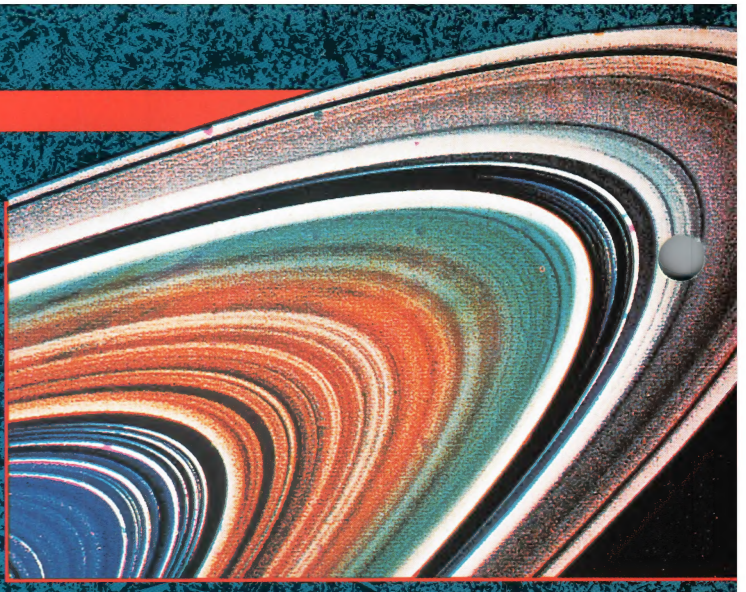
Mark Franklin

Some of the most striking natural constructed, the importance of symmetry becomes apparent. The wings of a bird are identical, as are the two halves of a bridge span. If they were not, one half would be inferior to the other and the structure of the whole would be needlessly weakened.

To understand the idea of symmetry forms are crystals. They are classified according to their symmetries. A crystal that is a combination of a cube and an octahedron, for example, can be combined to give a form resembling a cube with its corners bevelled off. Such a shape has threefold and fourfold symmetries.

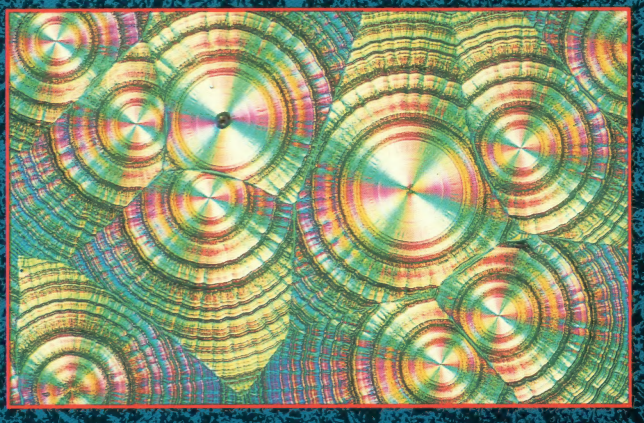
Manfred Kage/SPL

A human fingerprint, *showing tiny ridges on the skin arranged in a pattern unique to each human being.*



The rings of Saturn, *photographed by US Space probe Voyager 2. Ice-covered particles of rock trapped in Saturn's orbit make up the rings.*

NASA/SPL



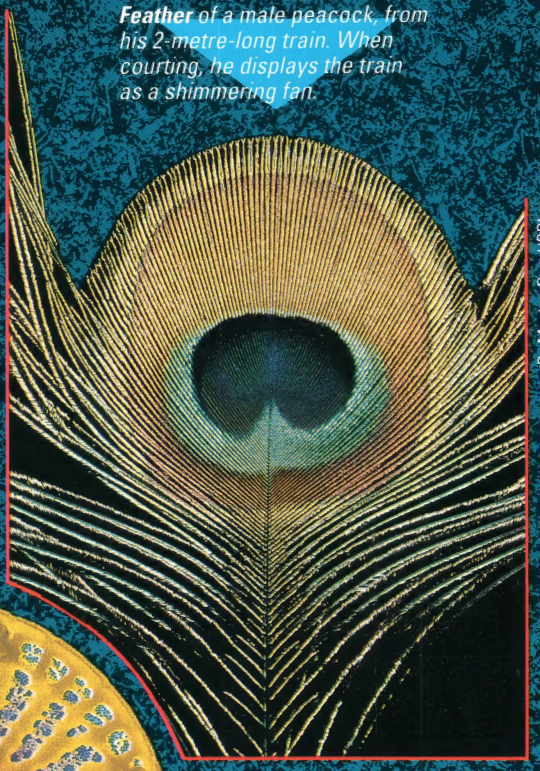
David Parker/SPL

Vitamin C *crystals, magnified 14 times. Vitamin C, also called ascorbic acid, is found in vegetables and citrus fruits.*

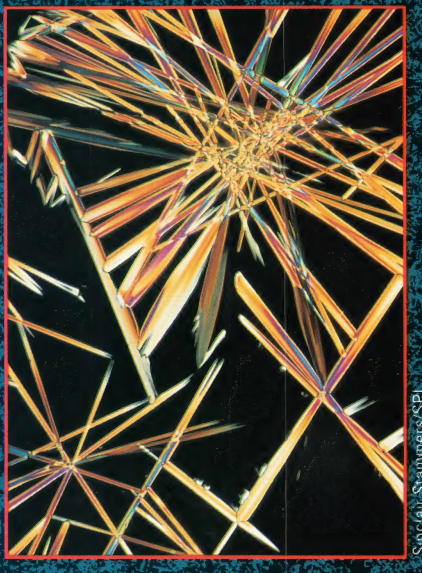
Crystals *of the stimulant caffeine, magnified 80 times. Caffeine is present in coffee and cocoa beans and in tea leaves.*

Simon Fraser/SPL

Sand ripples *on a beach at low tide in Achnahaird Bay, Scotland. The ripples are formed by the action of waves, as the tide comes in and then retreats, on the particles of sand that make up the beach.*



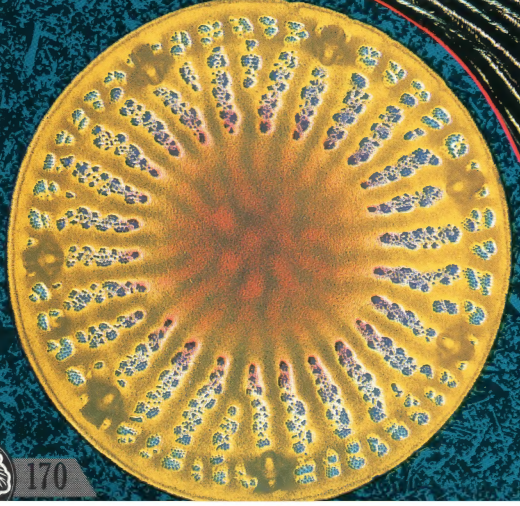
Feather *of a male peacock, from his 2-metre-long train. When courting, he displays the train as a shimmering fan.*



Dr Morley Read/SPL

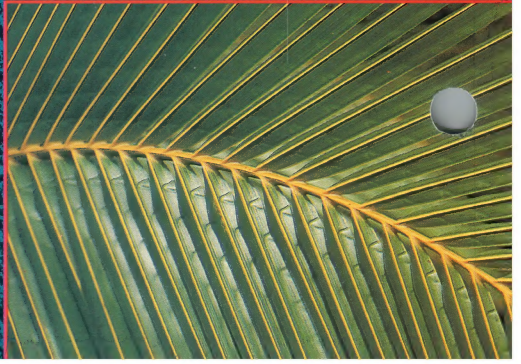
Sinclair Stammers/SPL

Palm leaves *may grow as long as 20 metres. The leaves are clustered in tufts at the top of the plant's woody stem, or trunk, or grow at intervals along the stem.*



Dr Ann Smith/SPL

A diatom, *a type of alga found in fresh and brackish water, consists of two valves that fit together like the top and bottom of a box. This cross-section through one of the valves reveals a radial pattern of pores.*



Tony Stone Photo Library, London